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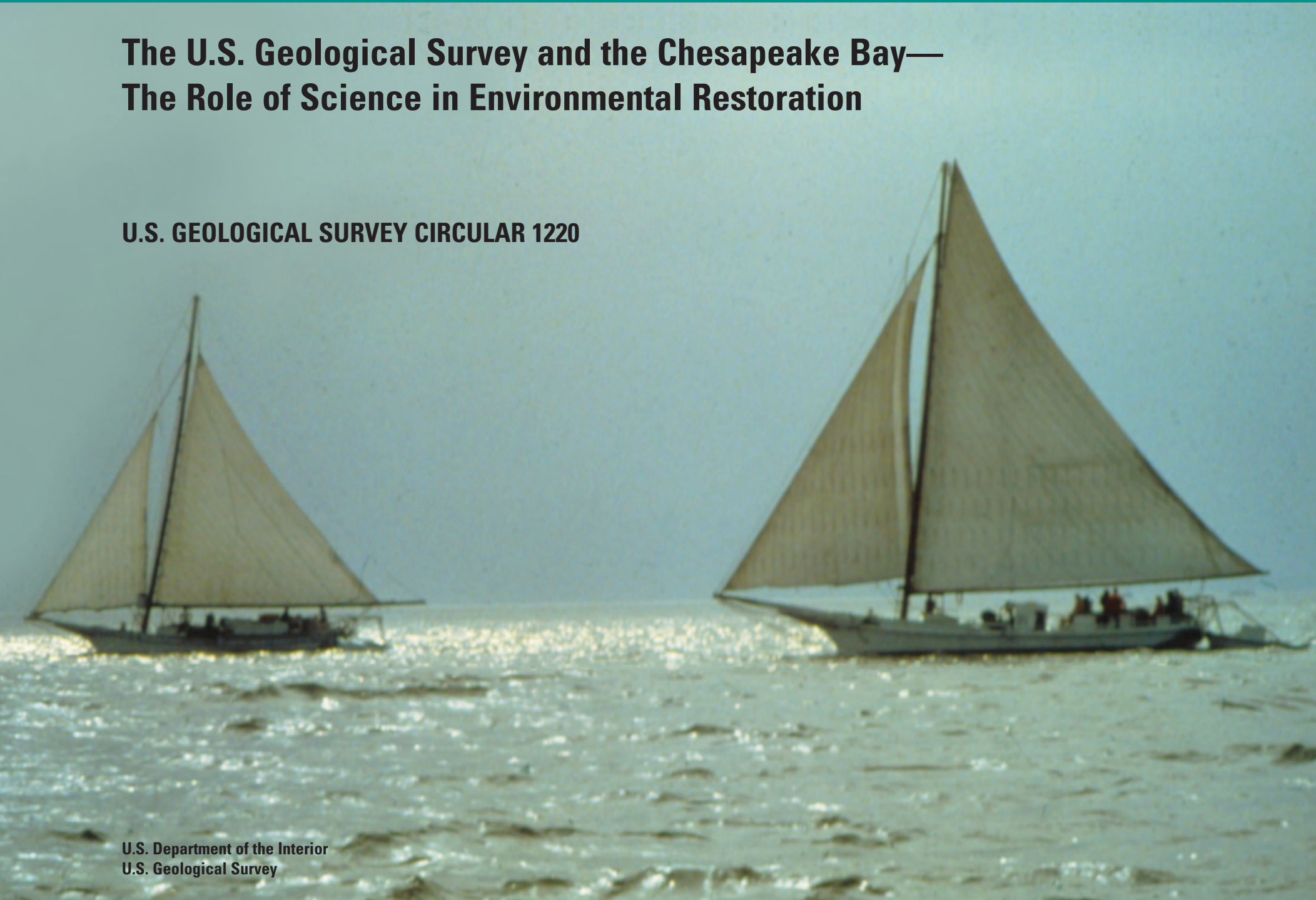
The U.S. Geological Survey and the Chesapeake Bay—The Role of Science in Environmental Restoration



U.S. GEOLOGICAL SURVEY CIRCULAR 1220

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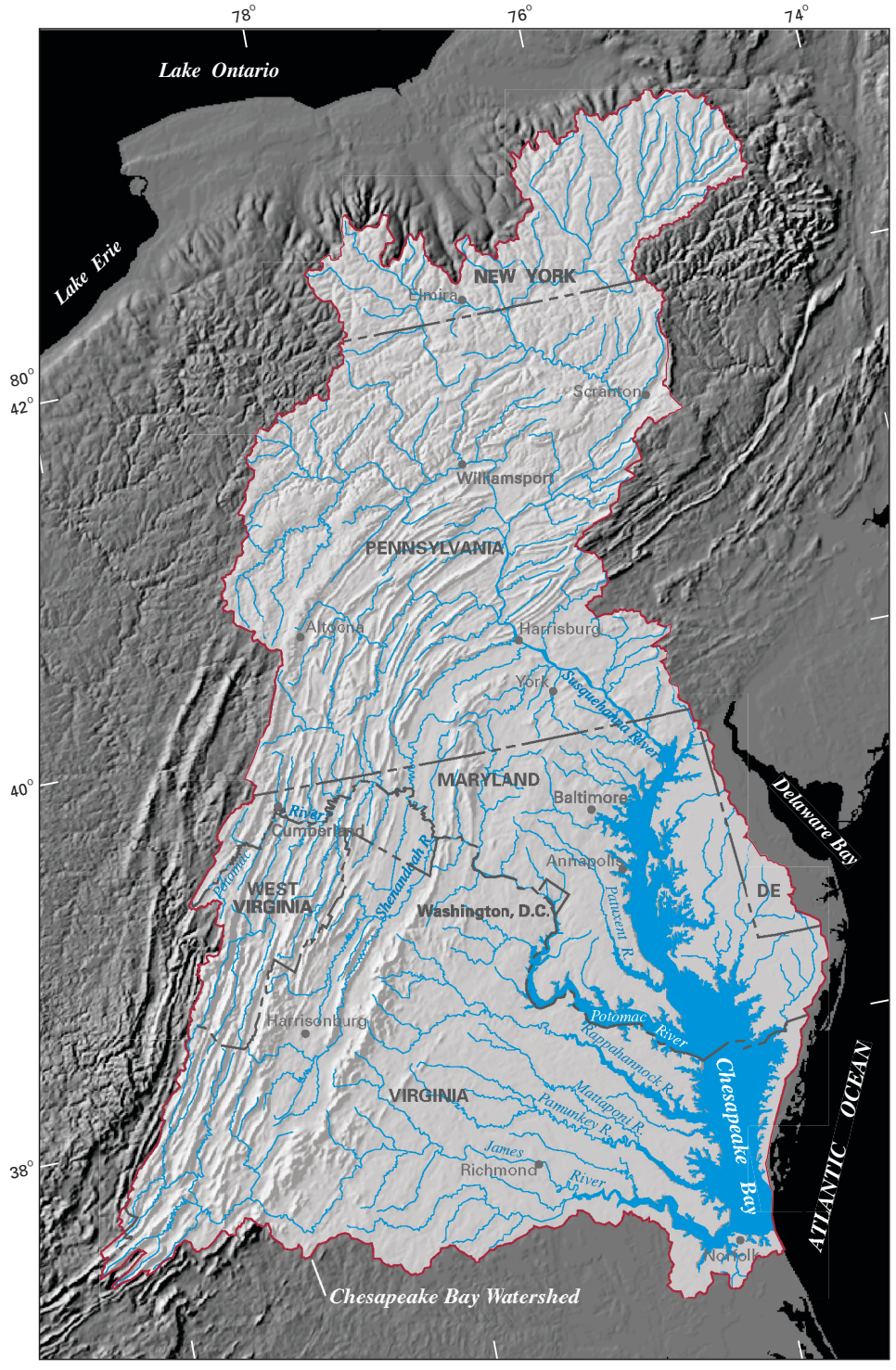
Cover. Skipjacks on Chesapeake Bay harvesting oysters.
Photograph from the Chesapeake Bay Program.



Shaded relief map of Chesapeake Bay watershed.

U.S. Department of the Interior
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The U.S. Geological Survey and the Chesapeake Bay—The Role of Science in Environmental Restoration

Edited by Scott W. Phillips

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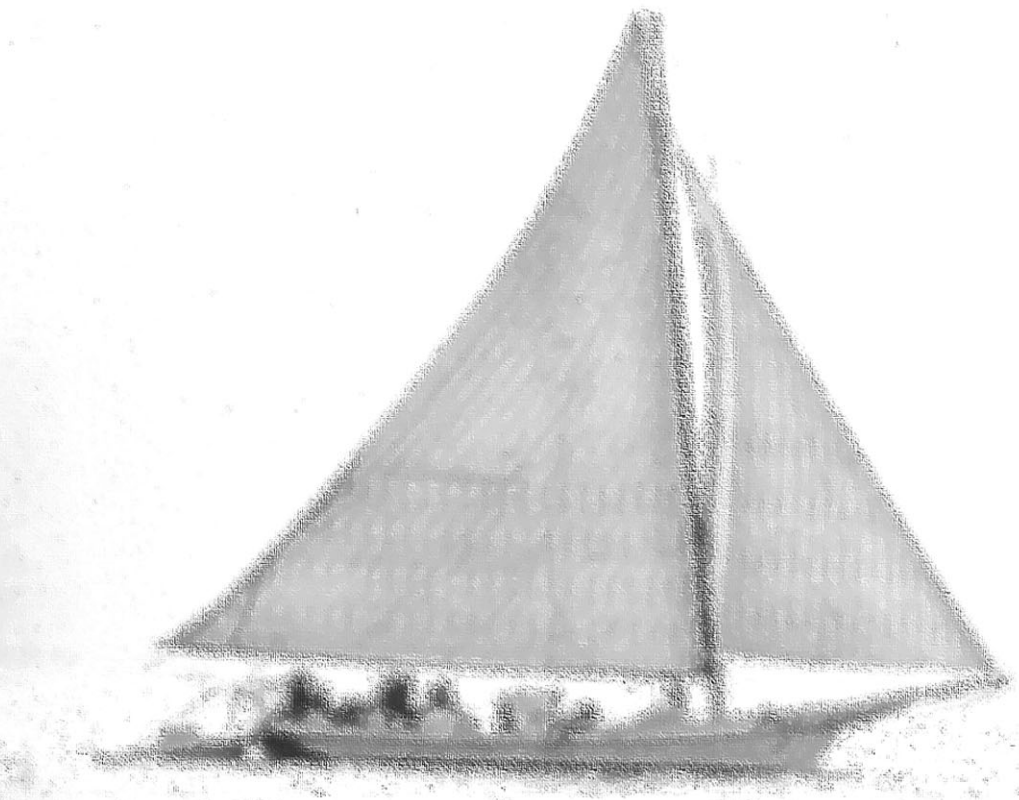
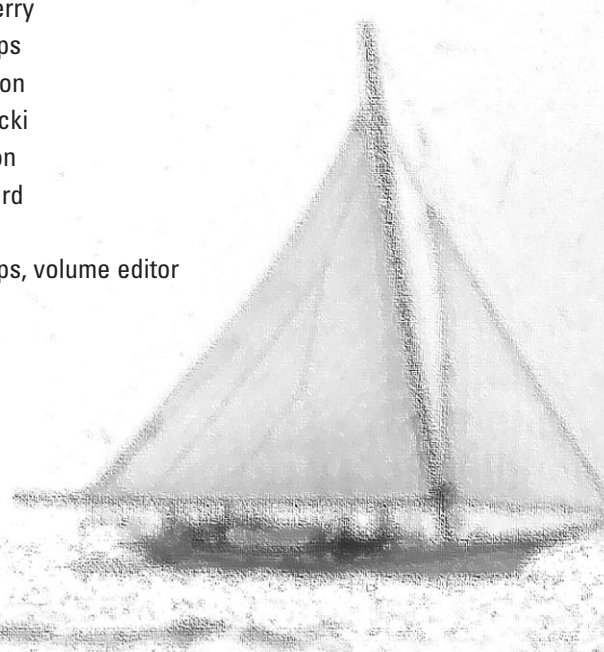
Contributing Authors

Roger A. Barlow
John W. Brakebill
John F. Bratton
Vicki S. Blazer
Johnkarl F. Bohlke
Owen P. Bricker
Steve M. Colman
Thomas M. Cronin
Cliff R. Hupp
Janet R. Keough
Jurate M. Landwehr
Michael J. Langland
Wayne L. Newell
Matthew C. Perry
Scott W. Phillips
Steve D. Preston
Nancy B. Rybicki
Nancy S. Simon
Debra A. Willard

Scott W. Phillips, volume editor





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Snow geese at Gibson Island.

Introduction

Problems Facing the Nation's Largest Estuary

The Chesapeake Bay is the Nation's largest estuary and historically has supported one of the most productive fisheries in the world. The bay is the spawning ground for 70 to 90 percent of the striped bass in the Atlantic Ocean. The 64,000-square-mile watershed of the bay provides vital habitat for migratory birds using the Atlantic Flyway (fig. 1). In addition to supporting aquatic communities and wildlife, the bay's watershed serves the economic and recreational needs of 15 million people. The fertile soils of the watershed support significant agricultural production. The agricultural products and other goods produced in the watershed are shipped through ports on the bay, such as Baltimore, Md., and Norfolk, Va., to the world. Unfortunately, the commercial, economic, and recreational value of the bay and its watershed has been degraded by poor water quality, loss of habitat, and overharvesting of living resources.

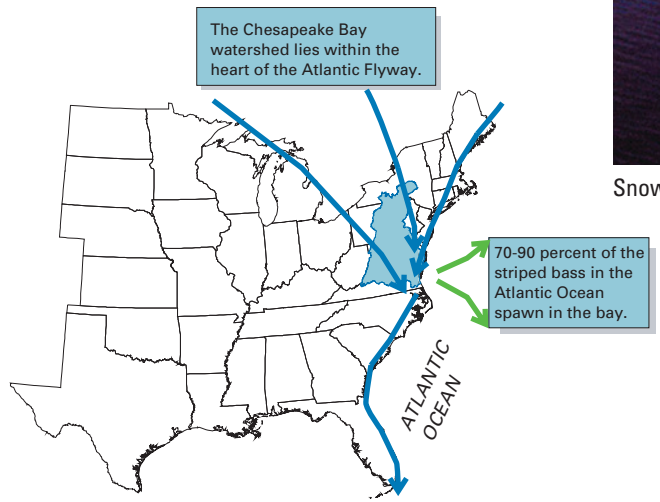


Figure 1. The Chesapeake Bay, the Nation's largest estuary, is the spawning ground for most of the striped bass in the Atlantic Ocean. The bay's watershed provides vital habitat and food for migratory birds using the Atlantic Flyway. Degradation of the water quality and habitat is causing declines in many of the bay's living resources and has resulted in the bay being listed as an impaired water body under the Clean Water Act. "Chesapeake 2000" is an agreement among the Federal Government, jurisdictions in the watershed, and the Chesapeake Bay Commission to restore the bay. The U.S. Geological Survey is providing critical science to support restoration of the bay and its watershed.

Several hundred years ago, this estuary teemed with life (Alliance for the Chesapeake Bay, 1998). Fish, shellfish, and water birds blanketed the bay, and underwater grasses grew so thickly they challenged navigation. The land contained in the watershed was home to a diversity of plants and animals, and forests covered 95 percent of the area. Today, the watershed barely resembles the land explored by European settlers in the early 1600's. Forests that filtered pollutants from the bay and its rivers have been cut down and replaced with cities, suburbs, and farms. Manmade pollutants, loss of vital habitat such as wetlands and underwater plants, and overharvesting of fish and shellfish have substantially reduced the abundance and diversity of living resources. For example, oyster populations in the bay have declined dramatically due to overharvesting, loss of habitat, and disease (fig. 2). Resource managers want to avoid a similar fate for the blue crab.

One of the biggest threats to the bay's water quality and the life that depends on it, ironically, is the bay's overabundance of a good thing—nutrients. The bay needs nutrients, primary nitrogen and phosphorus, to fuel life and stay healthy. These nutrients occur naturally in the watershed but are also found in human and animal wastes and commercial fertilizer. As human population has grown in the watershed, with an accompanying growth in agriculture, an overabundance of nutrients has entered the bay. Excess nutrients have stimulated algal blooms; as the blooms decompose, they use up dissolved oxygen and cause large areas of low dissolved oxygen in the bay. The low dissolved oxygen has killed many of the bottom-dwelling animals, such as oysters, in the bay. The algal blooms, along with sediment eroding from the land, also block sunlight needed by underwater grasses (also known as submerged aquatic vegetation or SAV). Without sunlight, the bay grasses die, removing important habitat for fish and shellfish and food for waterbirds. Because of the continued problems with excess nutrients and sediment, the bay was listed as an "impaired water body" in 1999 under the Clean Water Act. Improvements to water-quality conditions in the bay must be met by 2010, or regulatory approaches to achieve these standards will be implemented.

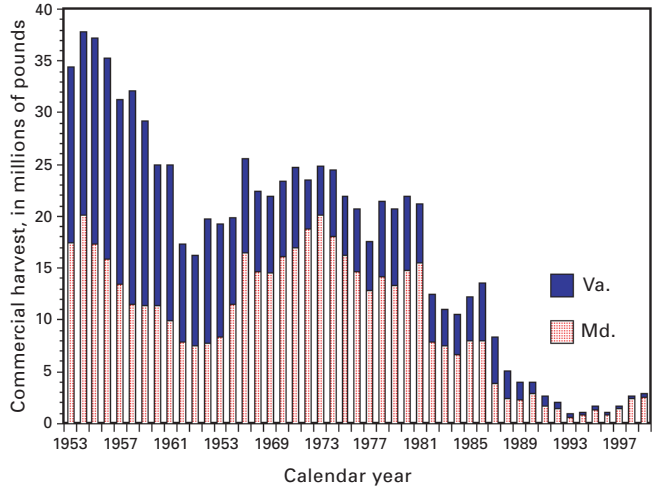


Figure 2. At one time, the Chesapeake Bay provided the Nation's largest harvest of oysters. Subsequent declines in oyster populations are the result of habitat loss, disease, and overharvesting. Efforts are being made to improve habitat conditions for oyster populations and other living resources in the bay. Data from the Chesapeake Bay Program.

Skipjacks on the Chesapeake Bay harvesting oysters. Photograph from the Chesapeake Bay Program.

Restoration Efforts of the Chesapeake Bay Program

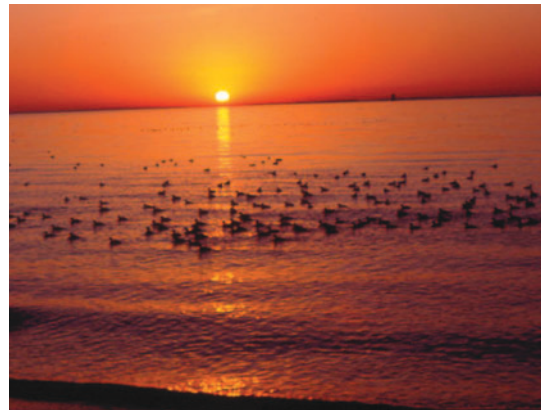
Since the early 1980's, the Chesapeake Bay Program (CBP), which is a partnership among Maryland, Virginia, Pennsylvania, the District of Columbia, the Federal Government, and the Chesapeake Bay Commission, has been formulating and implementing restoration goals to restore living resources, minimize habitat loss, and reduce the amount of nutrients, sediment, and toxic substances entering the bay. While progress has been made, the CBP has recognized the need for enhanced restoration efforts. Therefore, the CBP completed "Chesapeake 2000," a new agreement that revises and establishes new restoration goals for the next 10 years in the bay and its watershed. The restoration goals focus on achieving sound land use to reduce nutrient, sediment, and toxic substances entering the bay to restore living resources and their associated habitats. The goals are challenging and in many cases may be difficult to achieve without increased scientific information documenting the human and environmental causes of the ecosystem degradation. Such information is critical to effectively formulate strategies to meet and measure achievement of the restoration goals.

Role of the U.S. Geological Survey

The U.S. Geological Survey (USGS) Chesapeake Bay Science Program has the critical role of providing unbiased scientific information to be used in helping to formulate, implement, and assess the effectiveness of restoration goals in the bay and its watershed. The USGS began studies in the bay area in the late 1970's to document the amount and trends of nutrients entering the bay and the factors affecting the degradation of SAV. The USGS became a Federal partner in the CBP when the program was formed in 1983. Efforts significantly increased in the mid-1990's, when the USGS adopted the Chesapeake Bay watershed as one of its National Ecosystem System Study areas (Phillips and Caughron, 1997). The increased USGS efforts strengthened collaborative endeavors with other Federal and State agencies.

To support the expanded scientific needs of Chesapeake 2000 and associated Department of Interior partners, the USGS recently revised its scientific goals to conduct integrated science to understand the complex interaction among land use, water quality, vital habitat, and living resources. The USGS, through multiple national programs, conducts research, monitoring, and modeling to meeting these revised science goals. The results of this work will improve CBP management models and approaches to restore the bay and its watershed.

This Circular has two objectives: (1) provide examples of how USGS science is being used to help formulate environmental policy and (2) to outline future goals of the USGS Chesapeake Bay Science Program. A summary of USGS findings that have been used to formulate environmental policy in support of bay restoration is provided in table 1. The next five sections in this Circular present the findings that are summarized in table 1. The final section, "Meeting the Needs of Chesapeake 2000," provides an overview of future USGS efforts to provide science to support the restoration of the bay and its watershed.



Sunrise at Gibson Island.

Table 1. Summary of Chesapeake Bay restoration information needs, U.S. Geological Survey (USGS) findings, and restoration applications.

Restoration information need	USGS findings	Restoration applications
To understand the effect of long-term changes in climate variability and man's activities on the bay ecosystem.	There have been wet and dry cycles over the past 500 years that have affected the salinity, dissolved oxygen, and water clarity of the bay. However, these water-quality conditions have severely degraded over the past 200 years in response to human-induced changes in the watershed. Human influence and a wet period beginning in 1970's may be the combined causes for dissolved oxygen and water clarity being at their worst levels in the past 500 years.	Study results are being used to help set new water-quality standards for the bay. Results suggest that restoration efforts may not meet target dates because 200 years of human influence may not be reversed in 10 years and continued climate variability may overwhelm restoration activities.
To better define the sources and transport of nutrients and the influence of ground water.	The USGS has completed a watershed model that identifies the location of nutrient sources and their transport to the bay. Ground water was found to contribute a significant amount of water and nitrogen to streams and rivers entering the bay.	The Chesapeake Bay Program (CBP) is working to incorporate the influence of ground water into management models. Better targeting of locations to achieve nutrient reduction is being considered on the basis of these model results.
To reduce nutrients entering the bay over time to improve dissolved-oxygen conditions.	Although nutrient-reduction actions have been implemented since the mid-1980's, nutrient loads are not decreasing in many rivers entering the bay. Some of the factors responsible are steady or increasing trends in streamflow and the slow movement of nitrogen through ground water.	Resource managers are working to accelerate actions because of the slow improvement in water quality.
To understand the effect of the Susquehanna reservoir system on sediment delivery to the bay.	A large amount of sediment is trapped by the reservoirs on the lower Susquehanna River. Two of the reservoirs have reached their sediment storage capacity, and the third will reach capacity in 20 to 25 years. Once the capacity is reached, sediment and phosphorus loads will increase and degrade water clarity and submerged aquatic vegetation (SAV) in the upper bay.	A task force with USGS representation was formed to develop and recommend solutions to prevent the reservoir from reaching its storage capacity.
To understand changes in sedimentation in the bay and the relation to water clarity.	Sedimentation rates in some areas of the bay have increased four- to fivefold since the 1800's in response to timber harvesting and increases in agricultural and urban lands.	This information, along with future studies of the sediment sources affecting water clarity, will be used by the CBP to develop sediment-reduction strategies. These scientific findings will be integrated through a technical workgroup being co-chaired by the USGS.

Restoration information need	USGS findings	Restoration applications
To define the factors affecting SAV.	Information was compiled and interpreted for CBP to set light requirements for SAV in different salinity zones of the bay. Investigations also showed that presence of SAV-generating materials (seeds, propagules) is an important factor for survival of SAV. Finally, investigations revealed that SAV has returned in some areas of the Potomac but original species have been replaced by species that may not have the same food and habitat value to water birds and fishery resources.	The information is being used to set water-clarity goals and expanded goals for restoring SAV.
To define the occurrence of contaminants in the bay watershed.	Sampling indicates the presence of arsenic and antibiotics in some rivers. Antibiotics may be reducing microbial populations that break down nutrients and contaminants.	Information will be used for the Toxic-Reduction Strategy.
To document the effect of contaminants on water birds.	Initial results from USGS and U.S. Fish and Wildlife studies suggest that pesticide concentrations are below thresholds that cause adverse reproductive effects for some water birds.	The results are being used to develop strategies for the Toxic Regions of Concern in the bay watershed (Baltimore Harbor, Anacostia River, and Elizabeth River).
To understand the decline in water bird populations.	Many of the water bird populations have decreased in the bay watershed due to loss of SAV and other habitat. Studies showed that some species have been able to switch from SAV to clams as a primary food source resulting in more stable populations.	Results of these and other food-web studies are being used to develop management plans for the bay's living resources.
To define the factors affecting fish health and the relation to *Pfiesteria.*	While fish kills are related to *Pfiesteria*, the lesions on menhaden in the lower Eastern Shore are caused by invasive fungus *(Aphanomyces invadans*). Further investigations are addressing the factors causing the fish to be susceptible to fungus and *Pfiesteria*.	Resource managers are using these results to help revise management practices in the watersheds where *Pfiesteria* has been a concern and to develop multispecies management plans.
To provide science for ecosystem restoration strategies.	The USGS has now assumed coordination of monitoring and quality assurance activities at the request of CBP and increased representation on the technical subcommittees of the CBP.	USGS participation in the CBP provides direct application of science to formulate and evaluate the effectiveness of ecosystem restoration goals.

High water flow of the Potomac River near Washington, D.C.

Long-Term Changes in Climate Variability and Human Activities

Natural influences, such as climate variability, have affected the bay ecosystem since its development thousands of years ago. Documenting the influence of climate variability over long periods of time is helping to determine the relative influence of man's activities on the bay ecosystem. The CBP is using the mid-1980's as a baseline period to understand the effect of human activities on degradation of the bay ecosystem and watershed. However, human activities have been affecting the bay ecosystem for several hundred years as population increased and land use changed. Understanding the influence of both climate variability and human activities over time will help resource managers formulate achievable restoration goals and understand how the bay ecosystem may behave in the future.

Influence of Climate Variability on River Flow and Salinity

Climate variability affects the amount of rainfall and associated streamflow that enters the bay. Streamflow entering the bay is the primary control on salinity, stratification of the bay's waters, and pollutant loads. Changes in salinity affect the distribution of SAV and fish and the health of bottom-dwelling organisms such as oysters. Stratification prevents oxygen-rich water near the surface from mixing with oxygen-poor (anoxic) water below. Without enough oxygen, many aquatic species either die or leave the area. The amount of stratification depends upon the seasonal river flow and frequency of summer storms. Streamflow is also the primary factor affecting the amount of nutrients and sediments entering the bay that decrease oxygen levels and water clarity for living resources.

USGS researchers have documented changes in natural climate variability and the effect of these changes on water quality over the last few thousand years by studying geochemical and biological indicators in the sediments. Numerous wet-dry cycles have been identified during the last 500 years by studying sediment cores that document changes in bay organisms that are sensitive to salinity (fig. 3) (Cronin and others, 2000). Salinity has fluctuated as much as 10 to15 parts per thousand during the wet-dry cycles, with the highest salinity levels during the "megadroughts" of the early 16th and 17th centuries. These megadroughts exceeded those of the 20th century in severity. A long period of wetter conditions started in the early 19th century and lasted almost 100 years. Streamflow data collected since the 1930's (fig. 4) indicate that fairly normal hydrologic conditions existed in the bay during the 1940's and 50's. A dry period occurred in the 1960's, with wetter and more variable conditions beginning in the 1970's. The 1970's, in particular, had high-flow conditions, and the 1990's have shown a large degree of variability, with high-flow years mixed with relatively drier years. These wetter conditions, along with the effects of increased nutrients and sediment, may have been the main cause for the declines in dissolved oxygen and water clarity in the bay that were documented in the 1970's and that remain today.

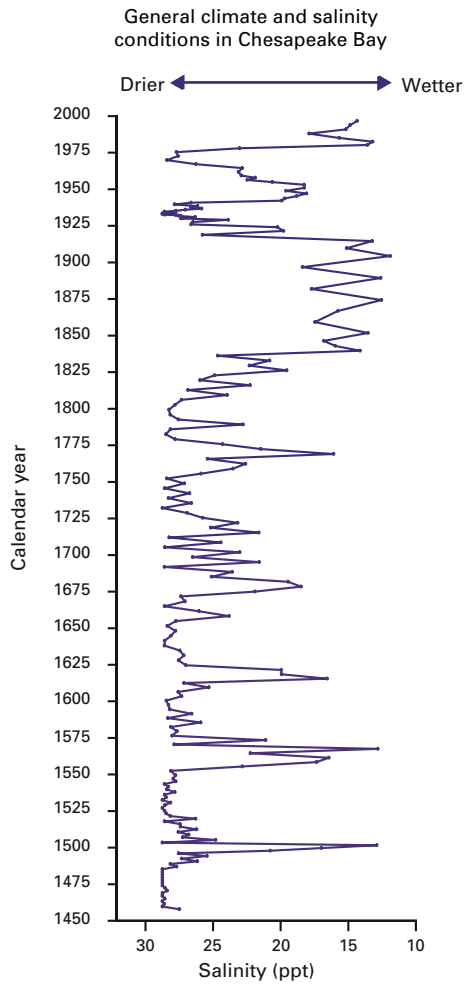


Figure 3. Climate variability affects the amount of rainfall in the bay watershed, which in turn influences salinity and delivery of pollutants to the bay. The U.S. Geological Survey has identified wet-dry cycles over the past 500 years that have resulted in changes in salinity, dissolved oxygen, and water clarity in the bay. These natural cycles in climate variability must be documented to understand the influence of human activities on the bay ecosystem so that realistic restoration goals and associated water-quality standards can be developed. This graph depicts changes in salinity (in parts per thousand (ppt)) off the mouth of the Patuxent River in the Chesapeake Bay. (From Cronin and others, 2000.)

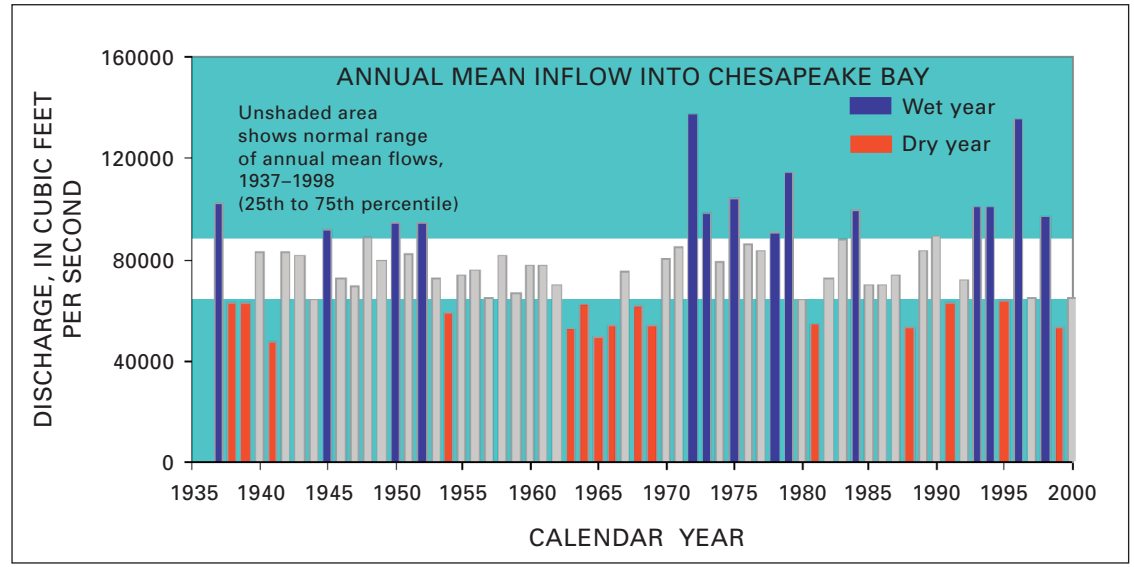


Figure 4. The U.S. Geological Survey has measured streamflow into the Chesapeake Bay since 1937. The long-term record helps to explain changes in living-resource populations and water quality in the bay. As shown in this graph, streamflow has increased and become more variable since the 1970's. The streamflow increase and the effects of increased nutrients and sediments have contributed to degrading dissolved-oxygen and water-clarity conditions in the bay.

Sediment runoff near Lancaster, Pa.

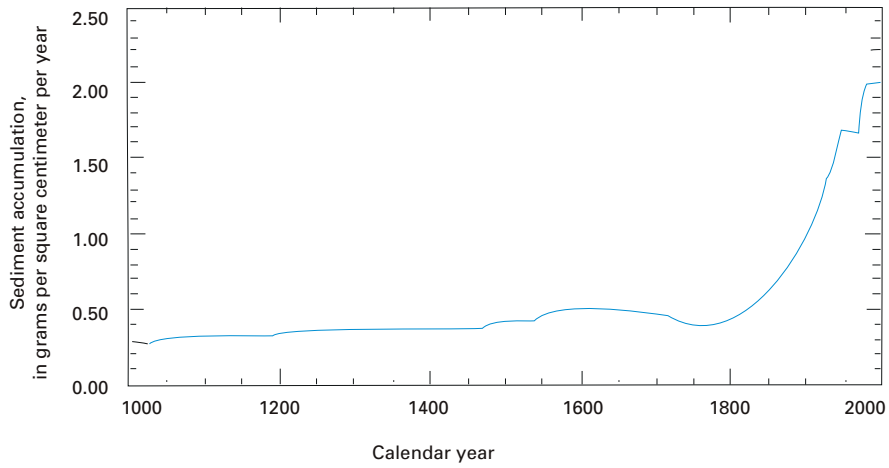


Figure 5. The rate of sediment accumulation in some areas of the Chesapeake Bay has increased dramatically over the past 200 years. The increase is due to a change in land-use practices, including clear cutting of forests and an increase in agricultural and urban lands. The increased sedimentation has resulted in degraded water clarity in the bay, which has adversely affected submerged aquatic plants and oyster populations. (From Colman and others, 1999.)

Effect of Climate and Population Growth on Dissolved Oxygen and Water Clarity

Dissolved oxygen is influenced both by climate variability and increased nutrient inputs arising from population increases and land practices over the past 400 years. Geochemical and biological indicators suggest that summer oxygen concentrations in Chesapeake Bay have fluctuated over time, including the pre-colonial period, but that the extent of low dissolved oxygen increased in the 1970's (Cronin and others, 2000). Since the 1970's, some biological indicators of low dissolved oxygen have become the dominant species in many parts of the midbay where oxygen depletion occurs (Karlsen and others, 2000). This degradation of dissolved oxygen is attributed to the combined effects of increased river flow into the bay occurring in the 1970's (fig. 4) and larger amounts of nutrients from increases in human population.

Water-clarity conditions in the bay during the late 19th century may have been worse than at any other time over the past few thousand years (Cronin and others, 2000). Some biota disappeared entirely from the bay, while others, which are present in turbid waters, became dominant components of some bottom-dwelling and phytoplankton (algal) communities. The water-clarity degradation was probably related to increases in sediment accumulation, which grew by a factor of four to five, beginning about 1750–1800 (fig. 5) (Colman and others, 1999). The increase in sediment accumulation rates is closely linked to the loss of forested lands in the watershed due to agricultural and urban growth. USGS information on long-term changes and variability in dissolved oxygen and water clarity is being used to help establish new water-quality goals for the bay.

Restoring Water Quality by Reducing Nutrients

Nutrients have been one of the most intensively studied environmental stressors on the health of the bay ecosystem because of their significant effects on dissolved oxygen and water clarity. Reduction of nutrients is difficult because most nutrients are from diffuse nonpoint sources, including agricultural land, urban development, and the atmosphere (fig. 6). These nonpoint sources are more difficult to effectively monitor, evaluate, and control than point sources, such as discharge of sewage and industrial waste. The CBP established a goal in 1987 to reduce controllable nutrient loads into the bay by 40 percent by the year 2000 to improve dissolved-oxygen levels. The goal was based on the results of computer models, which indicated that a 40 percent reduction in nutrients would improve dissolved-oxygen levels needed to sustain living resources in the bay. Unfortunately, environmental data collected since 1985 do not show a significant improvement in the summer dissolved-oxygen conditions. An understanding of the sources, transport, and delivery of nutrients from the watershed to the bay is critical to successfully revise the nutrient-reduction strategies that are necessary to attain dissolved-oxygen standards by 2010. While nitrogen and phosphorus are the primary nutrients of concern, nitrogen is emphasized in the following discussion because of its movement through ground water.

Effect of Land Use and Natural Processes on Nitrogen Concentration

Both land use and natural processes affect the occurrence and distribution of nitrogen in streams throughout the bay watershed. Nitrogen concentrations in streams range from less than 1 milligram per liter (mg/L), which is considered to be the natural level, to about 12 mg/L (Langland and others, 1995). The USGS integrates nutrient-concentration data and streamflow measurements to compute the amount of nutrients (known as loads) and relates these loads to nutrient sources by using watershed models. A USGS watershed model, "SPARROW" (SPAtially Referenced Regressions On Watershed attributes), provides further data on the distribution of nitrogen loads and their relation to nitrogen sources in more than 1,400 streams in the watershed (Preston and Brakebill, 1999). High nitrogen loads, generally associated with agricultural inputs, occur in an arc-shaped area from central Virginia through south-central Pennsylvania and along the Eastern Shore of Maryland and Virginia (fig. 7*A*). SPARROW also provides an estimate of nutrients ultimately reaching the bay (fig. 7*B*). Areas of high nitrogen delivery are again associated with agricultural and point sources. Model results indicate that, on a median basis, about 20 percent of the nitrogen sources actually reach the bay.

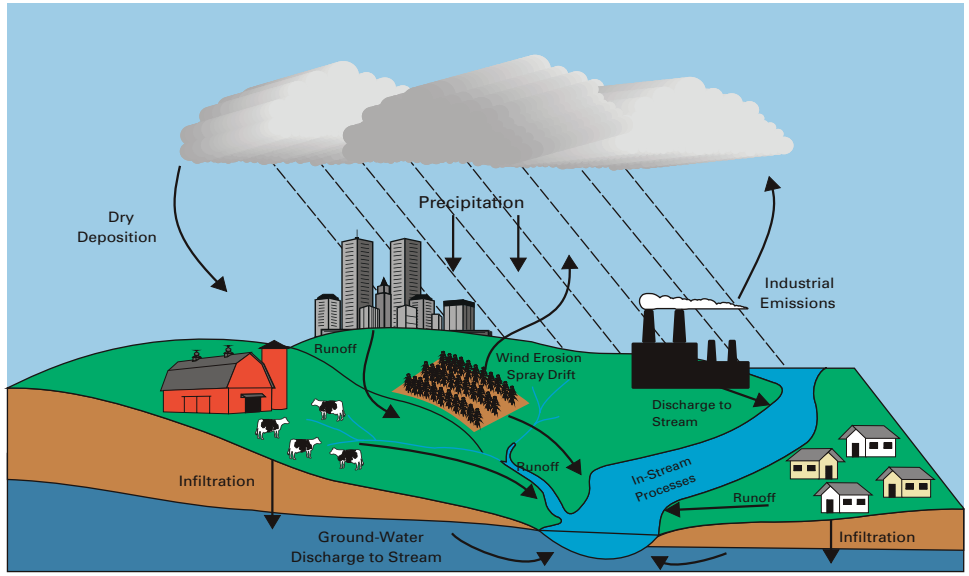


Figure 6. U.S. Geological Survey studies help identify the amount of nutrients from urban and agricultural sources that enter the ground water and streams and discharge into the Chesapeake Bay. Once in the bay, the overabundance of nutrients causes algal blooms, which block sunlight and lower dissolved-oxygen levels. (From Phillips and others, 1999.)

Agricultural land in western Howard County, Md.

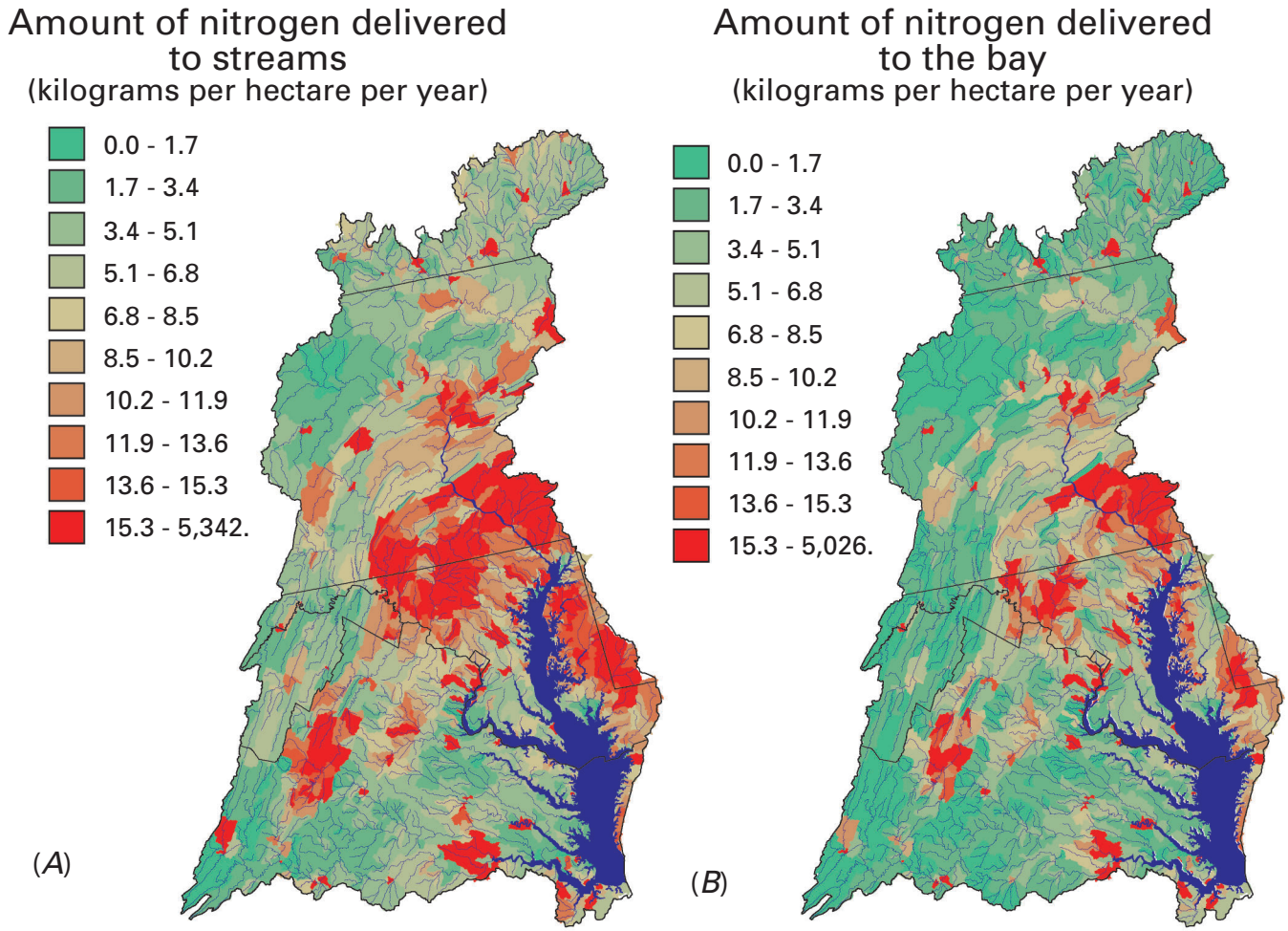


Figure 7. The U.S. Geological Survey constructed a watershed model to estimate nutrient delivery to the Chesapeake Bay. Nitrogen from major sources is first delivered to streams in the watershed (*A*). The areas in red show streams having the highest amount of nitrogen. Once in a stream, nitrogen concentrations will often decrease before reaching the bay because of uptake by algae and other processes. The areas that deliver the most nitrogen to the bay (*B*) need to be targeted for the most intensive nutrient-reduction efforts. (From Preston and Brakebill, 1999.)

Land-cover information representing different periods is helpful to understand how land-use changes affect nutrient sources and trends. The USGS has cooperated with several other agencies to produce land-cover data through the Multiple Resolution Land Characterization program (fig. 8). The CBP and USGS are using land-cover information from this program as the basis for constructing models that represent mid-1980's, early 1990's and late 1990's conditions in the bay watershed.

Effect of Streamflow and Nutrient Sources on Nitrogen Trends

Changes in streamflow lead to variations in nutrients over differing periods, such as storm events, seasons, and longer periods of time. These three time periods are important to understanding the delivery of nutrients to the bay. Transport of nutrients in rivers usually increases substantially during storms. For example, the high flow in the Susquehanna, Potomac, and James Rivers during January 1996 carried roughly three times the amount of flow, six times the amount of phosphorus, and three times the amount of nitrogen than is carried in an average January (Zynjuk and Feit-Majedi, 1996). Fortunately, this flood occurred in winter, a time when farmland rich in nutrients was frozen and the potential amount of nutrients that could be washed into the bay was decreased. The nutrients that did reach the bay did not have a negative effect because temperatures were too low to produce large algal blooms. This flood contrasts with Tropical Storm Agnes, which delivered large amounts of nutrients and sediment to the bay in June 1972. The large influx during the summer period resulted in loss of SAV because of poor water clarity related to the increased sediment and nutrients.

Figure 8. Land-cover data for the Chesapeake Bay watershed is needed to determine the influence of land cover on pollutant concentrations and for watershed-management models. The U.S. Geological Survey provides land-cover data for the bay watershed through cooperation with other Federal and State agencies. A poster of this image ("The Chesapeake Bay Watershed") is available by calling 1–888–ASK–USGS.

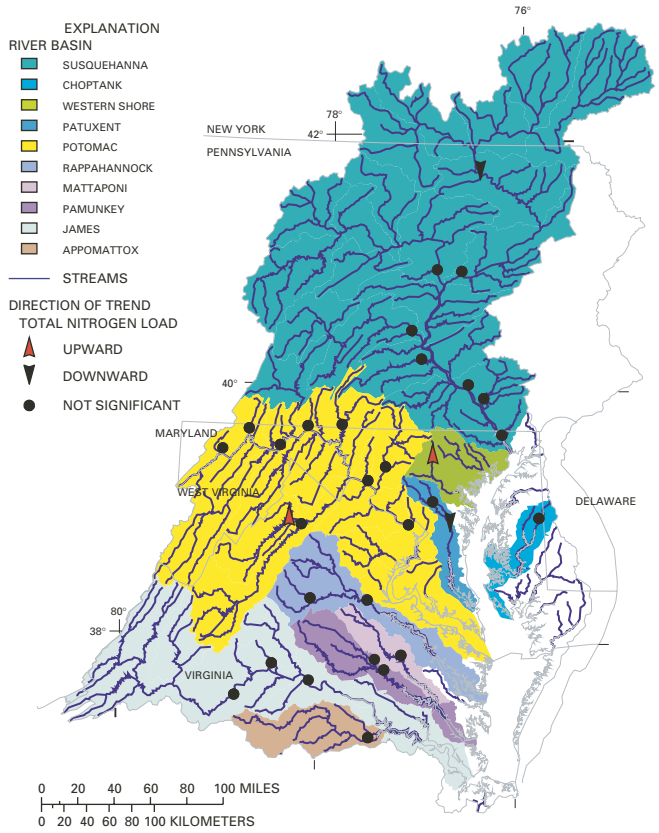


Figure 9. The amount and trends in total nitrogen loads have been measured at the Chesapeake Bay watershed sites shown above since 1985. Trends at many of these sites for 1985–99 do not show a decrease in the amount of nitrogen in the rivers discharging to the bay in spite of efforts to decrease nutrients (from Langland and others, 2001). Reasons for the lack of improvement include high streamflow entering the bay in the 1990's, which increases nitrogen loads, the influence of ground water, and smaller than predicted reductions in nitrogen sources.

Nutrient concentrations in streams also vary throughout the year, with high concentrations often found in the winter and early spring. As temperatures in streams increase in the late spring and summer, the nutrient concentrations decrease because of the growth of plants and algae. The higher concentrations and larger amounts of streamflow during the late winter and early spring often result in the largest nutrient loads of the year.

Documenting the variability of nutrients during storms and seasons is needed to help determine long-term trends of nutrients entering the bay. The USGS, in cooperation with State and Federal partners, measures the streamflow and estimates the loads and trends of nutrients and sediments in the 9 major rivers entering the bay and at 24 associated sites in the watershed (fig. 9). The nutrient trends reflect both the influence of natural conditions, primarily the variability in streamflow, and the effectiveness of management actions to reduce nutrient concentrations and their associated sources.

As a baseline, the trend analysis uses the mid-1980's, when nutrient-reduction efforts began to be implemented. The majority of the sites studied did not have a trend in nutrient loads through 1999; that is, trends in nitrogen and phosphorus loads paralleled trends in streamflow (Langland and others, 2001). However, when the influence of streamflow is removed, the nitrogen and phosphorus concentration trends from 1985 to 1999 show declines at a majority of the sites. The analysis suggests that management actions are influencing the decrease in nitrogen and phosphorus concentrations; however, because of higher streamflow, the influence of ground water, and smaller than predicted reductions in nitrogen sources, nutrient loads are not decreasing (Sprague and others, 2000). The lack of change in nutrient loads to the bay over the past 15 years corresponds to a lack of significant improvement in summer dissolved-oxygen levels in the bay.

Contribution of Ground Water to Nitrate in Streams

Ground-water discharge to streams provides a large amount of flow that eventually enters the Chesapeake Bay. Some of the nutrients that are applied to the land surface, especially nitrate, infiltrate the underlying ground-water system and are transported through shallow aquifers and discharges to springs and streams, thereby increasing the nitrate load to streams. USGS findings show that ground water contributes more than half (54 percent) of the total annual flow of streams in the Chesapeake Bay watershed and about half of the total annual nitrate load (Bachman and others, 1998). The amount of ground-water discharge is not uniform throughout the bay watershed; discharge varies according to the different types of rocks present and the topography. For example, areas underlain by carbonate rocks in the Valley and Ridge province of the watershed had the highest amount of ground-water discharge to streams (fig. 10) (Bachman and others, 1998). Carbonate rocks can have open conduits that carry large amounts of ground water, which discharge back to streams. In contrast, areas of the Piedmont physiographic province (that is, the Mesozoic lowland), composed of relatively impermeable rocks, had the lowest amount of ground-water discharge to streams.

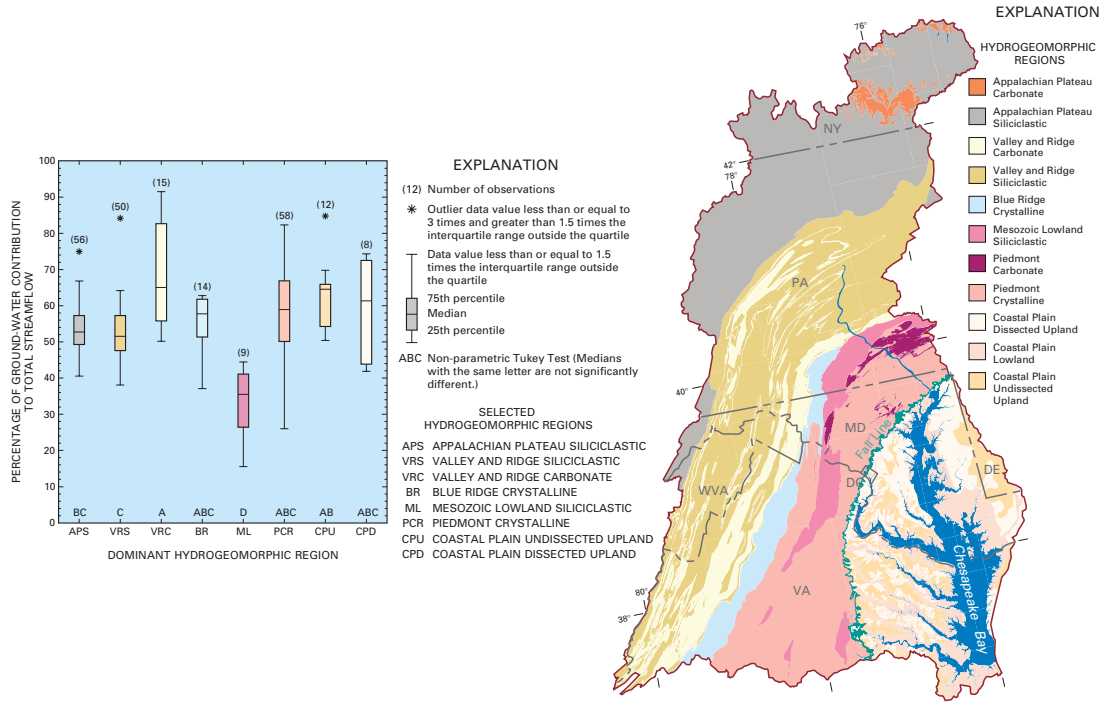


Figure 10. Studies by the U.S. Geological Survey determined that the amount of ground-water discharge to the Chesapeake Bay watershed varies according to the type of rocks present and the topography of the area. The highest amount of discharge to streams is found in areas of the Valley and Ridge province underlain by carbonate rocks; the lowest amount is found in the Piedmont province, which is composed of relatively impermeable rocks. (From Phillips and others, 1999.)

Nitrate concentrations in these different ground-water settings are related to land use and the composition of the rocks and sediments. On average, nitrate concentrations in ground water vary from 5 mg/L in agricultural areas, to 2 mg/L in urban areas, and less than 0.1 mg/L in forested areas (Ator and Ferrari, 1997). In addition to land use, nitrate in ground water is also controlled by the composition of rocks and sediment. For example, in the Coastal Plain of southern Maryland, some sediment that contains high amounts of organic materials and silt and low dissolved oxygen helps to remove nitrogen naturally (through a process known as denitrification) as it moves through the aquifer or discharges through the streambed sediment (Bachman and Krantz, 2000). Higher concentrations of nitrate are found in ground water in the Coastal Plain aquifer composed of more permeable sands and gravel, with little organic material and higher dissolved oxygen (Speiran and others, 1998).

USGS findings show that ground water moves relatively slowly through the shallow aquifers in the Chesapeake Bay watershed. Age dating of water collected from springs throughout the bay watershed shows the residence time (representing the total time for ground water to move through an aquifer) ranges from modern

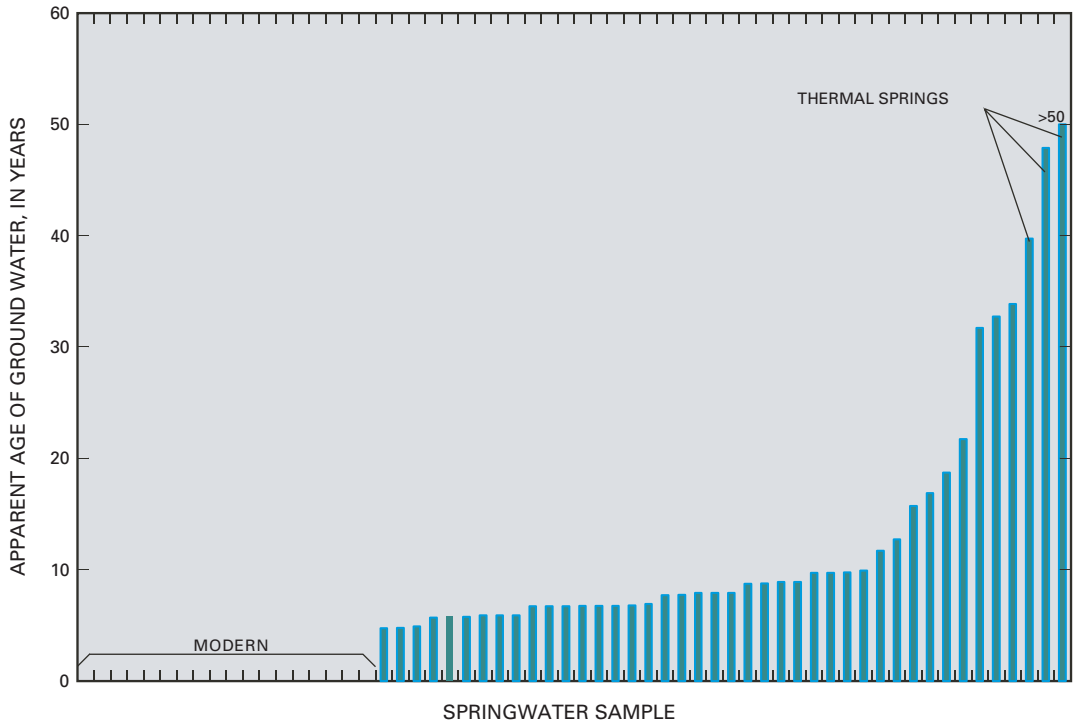


Figure 11. Nitrogen moves through the land surface, infiltrates the shallow ground water, and discharges into streams draining to the Chesapeake Bay. Understanding the apparent age of ground water will help determine the lag time between reducing nutrient sources and detecting a decrease in nitrogen concentration in a stream. U.S. Geological Survey findings indicate that the average age of most of the ground-water samples collected in 1996 from springs in the bay watershed is from modern to less than 10 years old. (From Focazio and others, 1998.)

(0–4 years) to more than 50 years, with 75 percent of the ages less than 10 years (fig. 11) (Focazio and others, 1998). The age of the ground water seems to be controlled by local geology and topography. The residence time also provides an estimate of the lag time between implementation of management actions to reduce nutrient loads and a distinguishable improvement in water quality.

Need for Targeting Nutrient-Reduction Strategies

The USGS findings show that variations in land use, watershed characteristics, streamflow, and ground water all affect the occurrence of nutrients in the watershed and their delivery to the bay. The most effective nutrient-reduction strategies are more targeted, local actions based on nutrient sources and the watershed and stream characteristics that affect nutrient delivery to the bay. For this reason, the States, through the CBP, are revising nutrient reduction strategies for the major watersheds draining to the bay.

Because nitrate moves slowly through ground water, there is a lag time between the reduction of nutrient sources and improvement of water quality in ground water and surface water. USGS studies confirm the need for consistent, long-term monitoring and analysis to define the factors affecting nutrient trends and to evaluate the effectiveness of nutrient-reduction strategies for the future.

Understanding the Relation Between Sediment and Water Clarity

Excess sediment is having an adverse effect on the living resources and habitats of the Chesapeake Bay and its watershed. Suspended sediment and phytoplankton growth due to excess nutrients have reduced water clarity below the thresholds needed to support SAV. Contaminants and potential pathogens associated with sediment can affect fisheries and other living resources. Excessive sedimentation can bury or degrade the vitality of oysters and other bottom-dwelling organisms and can degrade stream habitat. Finally, commercial shipping and recreational boating are threatened by the in-filling of shipping channels. The USGS is working with the CBP to determine sediment sources, transport, sites of deposition, and relation to water clarity and living resources in various parts of the bay and its watershed so that an effective sediment-reduction strategy can be formulated.

Sources and Transport of Sediment to the Bay

The major sources of sediment to the bay include (1) soil erosion and riverine transport, (2) shoreline erosion, (3) the ocean, and (4) biological production in the water column. All of these sources, along with resuspension of existing sediment, contribute to sediment deposition and associated poor water clarity in the bay (fig. 12). Sediment is generated in the watershed because of natural weathering of rocks and soils, accelerated erosion of lands and streams caused by agricultural and urban development, and resuspension of previously eroded sediments that are stored in stream corridors. USGS studies indicate that the three largest rivers entering the bay (Susquehanna, Potomac, and James; fig. 12) account for most of the sediment from the watershed; these three rivers deliver about 4 million tons of sediment per year (Langland and others, 1995).

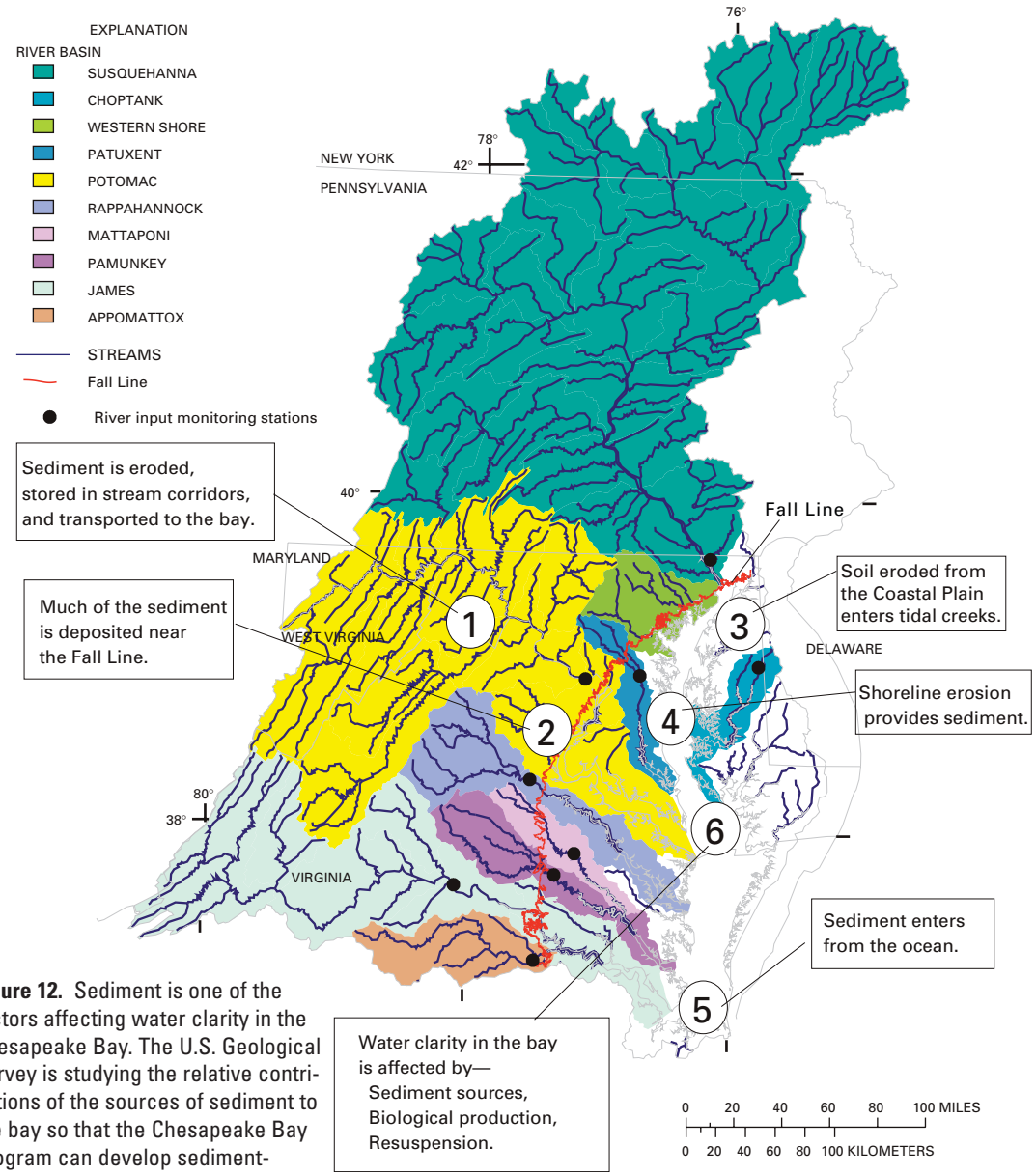


Figure 12. Sediment is one of the factors affecting water clarity in the Chesapeake Bay. The U.S. Geological Survey is studying the relative contributions of the sources of sediment to the bay so that the Chesapeake Bay Program can develop sediment-reduction strategies to improve water clarity for submerged aquatic vegetation.

Figure 13. Drainage ditches and channelization of some rivers on the Eastern Shore have resulted in nutrients and sediment being transported more quickly to the Chesapeake Bay. Another factor is the deforestation of land to support agricultural production. Forested areas trap substantial amounts of sediment and contaminants; when areas are cleared for agriculture, more sediment and nutrients are transported to the bay.

Most of the sediment in these large rivers is initially deposited near the Fall Line, which is the zone that separates the Piedmont from the Coastal Plain. The large amount of deposition here is due to both an abrupt reduction in stream gradient (less slope, so less stream velocity) and the influence of tides in the bay. In this zone, sediments and contaminants may be stored and altered biogeochemically before ultimately reaching the critical wildlife and fish nursery areas in the bay proper. Of the sediment generated in watersheds, nearly 90 percent is trapped for a period of time along streams before reaching saltwater (Meade and others, 1990). Sediment may take years, even centuries, to be transported to the bay because of continual deposition and resuspension in stream corridors.

In contrast to the large rivers, many midsize and smaller rivers originating in the Piedmont or Coastal Plain have extensive forested areas that trap substantial amounts of sediment and contaminants (Hupp and others, 1993). Recently measured sedimentation rates are highest along rivers, such as the Patuxent and Chickahominy, that receive runoff from urbanized areas. Both the Patuxent and Chickahominy Rivers are typified by high-gradient headwaters originating in the Piedmont, and both have a high load of inorganic suspended sediments. In contrast, many rivers that originate on the Coastal Plain, where the stream gradient is very low throughout the watershed, transport very little mineral sediment but contain high levels of dissolved organic material.

The USGS is studying two small Coastal Plain watersheds (Popes Creek, Va., and the Pocomoke River, Md.) that drain directly to the Chesapeake Bay to serve as analogs for understanding sediment in the bay. Results indicate that Popes Creek serves as an effective trap for sediment derived from forested and agricultural areas. Most of the sediment being eroded from fields and gulleys is stored just downstream in ravines and the flood plains of larger streams. In some areas, more than 6 feet of sediment has been redeposited in ravines, and only a minimal amount is reaching the tidal portion of the tributaries. In contrast, some Coastal Plain rivers, such as the Pocomoke, have been altered by extensive channelization to promote soil conditions for agriculture and suburban development (fig. 13). The channelization facilitates the mobilization and transport of sediments, much like a pipeline, whereas stream reaches that have not been channelized continue to trap sediments.

Sediment also plays an important role in transporting phosphorus and other contaminants in river systems (Simon and others, 1999). The amount of phosphorus depends on the source and on the geochemical reactions affecting phosphorus during transport. The rate at which the sediment and associated phosphorus are transported is important to assess the length of time needed for sediment- and nutrient-reduction practices to be effective.

Reservoirs and Sediment Delivery to the Bay

In addition to trapping sediments in stream corridors, reservoirs trap sediments in river systems. A reservoir system consisting of three consecutive hydroelectric dams on the Lower Susquehanna River was built between 1910 and 1931. The three reservoirs have been filling with sediment since their construction. The trapped sediments are available for delivery to the bay during floods. The three most recent large floods (June 1972, September 1975, and January 1996) carried about 36 million tons of sediment out of the reservoirs.

USGS studies have shown that the upper two reservoirs have reached sediment-storage capacity and generally no longer trap large amounts of nutrients and sediments. However, Conowingo Reservoir has not reached capacity and is trapping about 2 percent of the nitrogen, 40 percent of the phosphorus, and 70 percent of the suspended-sediment loads that would otherwise be discharged to the Chesapeake Bay (fig. 14) (Langland and Hainly, 1997). Although the Conowingo Reservoir is not yet full of sediment, little space remains. The time remaining until it becomes filled with sediment depends on factors such as (1) land-use and land-management practices, (2) the amount of rainfall, and (3) occurrences of large storm events. USGS scientists estimate that the three reservoirs will reach capacity in 20–25 years; this filling will result in an increase in sediment transported to the Chesapeake Bay that will further degrade water clarity and SAV. Solutions to address the problem are being addressed by a CBP-related task force.

Sediment Deposition in the Bay

USGS studies have shown that sediment accumulation rates are highest at the north end of the bay (the Susquehanna River being the primary source) and at the mouth of the bay (ocean source) and are lowest in the midbay segment. Sedimentation in the deep bathymetric channels of the bay tends to be faster than in the shallow-water areas. Sediment accumulation rates in some parts of the main channel of the bay have increased four- to five-fold since the mid-1700's because of deforestation in the watershed. Unfortunately, there has not been an overall study of the general contribution of each of the major sediment sources (riverine, shoreline, ocean, and biological production) to sediment deposition in the bay. Documenting the relation among sources, transport, and deposition in the bay is critical to successfully developing sediment-reduction strategies to meet water clarity standards. The USGS is working with the CBP to address these issues.

Water being released from the Conowingo Dam on the Susquehanna River during January 1996.

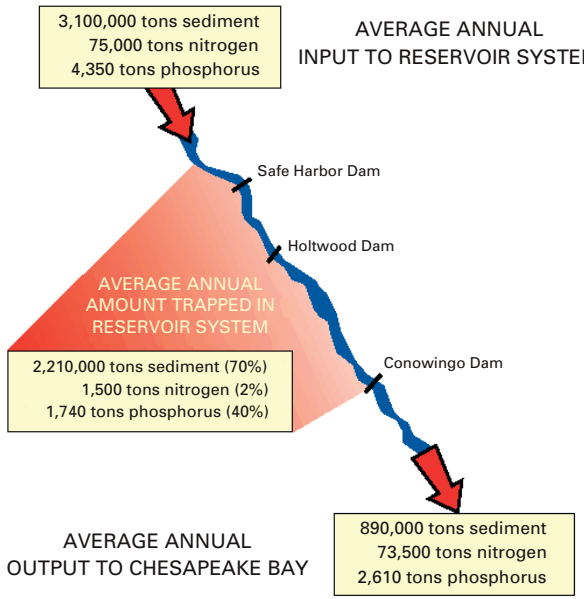


Figure 14. The Susquehanna is the largest river entering the Chesapeake Bay. A reservoir system on the lower portion of this river affects the amount of nutrients and sediment that reach the bay. Studies by the U.S. Geological Survey indicate that large amounts of sediment and phosphorus are trapped by the reservoirs; currently, about 70 percent of the suspended sediment is trapped, 2 percent of the nitrogen is trapped, and 40 percent of the phosphorus is trapped. However, the upper two reservoirs have reached their sediment storage capacity, and the Conowingo reservoir may reach capacity in about 25 years. The amount of nutrients and sediment transported to the bay will increase when the sediment storage capacity of all the reservoirs is reached. (From Langland and Hainly, 1997.)

Crabs from the Chesapeake Bay.

Environmental Stress on the Bay's Living Resources

Restoration and protection of living resources and their associated habitats in the bay and its watershed are among the primary goals of Chesapeake 2000. USGS studies help managers and policymakers understand the complex interaction among the environmental factors affecting SAV, fisheries, water birds, and food-web linkages in the biological communities.

Water-Quality Degradation and Submerged Aquatic Vegetation

SAV is an important part of the food web in the Chesapeake Bay, providing shelter and nursery areas for shellfish and finfish and food for a variety of water birds, fish, and invertebrates. Historically, SAV probably covered almost 600,000 acres of the bay bottom but now covers about only 10 percent of that amount (U.S. Environmental Protection Agency, 1999). The decline is related to the degradation of water clarity in the bay caused by increased sediment loads, increased nutrient loads, and the resultant algal blooms, which block sunlight.

The factors affecting SAV can be clearly demonstrated in the different salinity zones of the tidal Potomac River. SAV virtually disappeared from freshwater tidal Potomac in the late 1930's. The decline coincided with nutrient enrichment, increased algal concentrations, and extreme storm events (Carter and others, 1985; Rybicki and Carter, 1986). Through the 1970's, high nitrogen and phosphorus concentrations from the Blue Plains sewage-treatment-plant effluent fed frequent algal blooms (Callender and others, 1984) and decreased water clarity.

Beginning in the early 1980's, there was a reduction in nutrients and solids as the result of improved treatment-plant technology and a ban on phosphorus. By 1983, water quality improved enough to spark a resurgence of SAV in the freshwater zone (fig. 15). However, the species composition of the SAV changed. For example, the non-native species *Hydrilla* is beginning to dominate native species. The presence of the non-native species will have undetermined consequences on the biological communities that are dependent on SAV.

Unfortunately, the SAV recovery in the tidal freshwater zone was not sustained during the 1990's (fig. 15), and the USGS began to investigate other factors affecting SAV. The presence of SAV in an area during the previous year was found to be an important factor. Without SAV-regenerating materials (seeds, tubers, root masses) from the previous growing season or the introduction of plant material during the growing season, SAV failed to return to areas thought to have adequate water quality (Landwehr and others, 1999). This discovery led to revised efforts to reintroduce SAV through volunteer planting efforts in portions of the Potomac estuary.

Realizing that the factors affecting SAV were more complex than nutrient concentrations alone, USGS researchers have collaborated with the CBP to establish revised criteria for restoration of SAV. The CBP has worked to update SAV criteria by studying the percentage of light needed to support the plants. Studies of annual changes in SAV reveal that, when light penetration is high during the growing season, SAV coverage increases. However, at low light levels, SAV coverage response is not consistent. Once plant communities are established, some plant species can compensate for light limitations by elongating to the surface to reach sunlit areas. On the basis of a review of existing information,

specific water column light requirements for SAV were recommended in different segments of the bay (Carter and others, 2000). The results of this work were coupled with results from a multiagency team of scientists to revise the Chesapeake Bay SAV habitat criteria and establish new minimum light requirement criteria.

Sediment reducing light for submerged aquatic vegetation in the Patuxent River system.

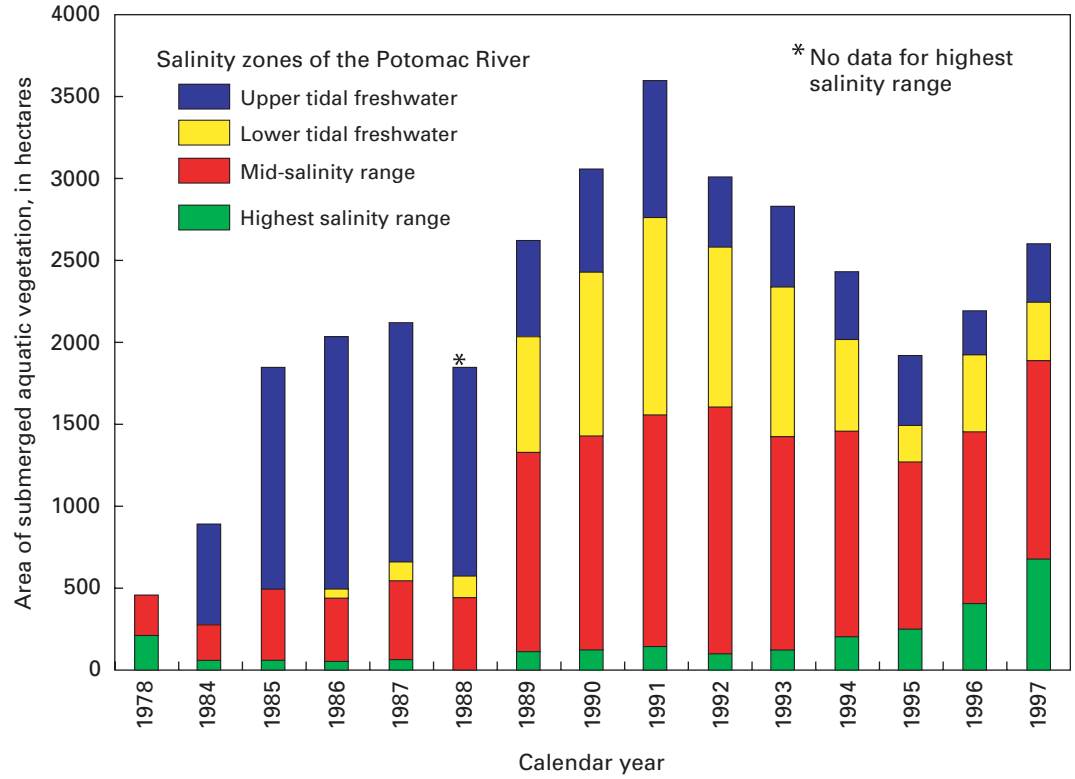


Figure 15. Changes in the amount of submerged aquatic vegetation (SAV) in different salinity zones of the Potomac River are shown for 1978–97. Beginning in the early 1980's, there was a reduction in nutrient enrichment as the result of improved technology at the Blue Plains sewage-treatment plant and a ban on phosphorus. By 1983, water quality improved enough to spark a resurgence of SAV in the freshwater zone. However, recovery was not sustained in the 1990's. Other factors, such as amount of light and availability of root material, are affecting the amount of SAV in the Potomac River and the Chesapeake Bay. (From Landwehr and others, 1999.)

Canvasbacks ducks.

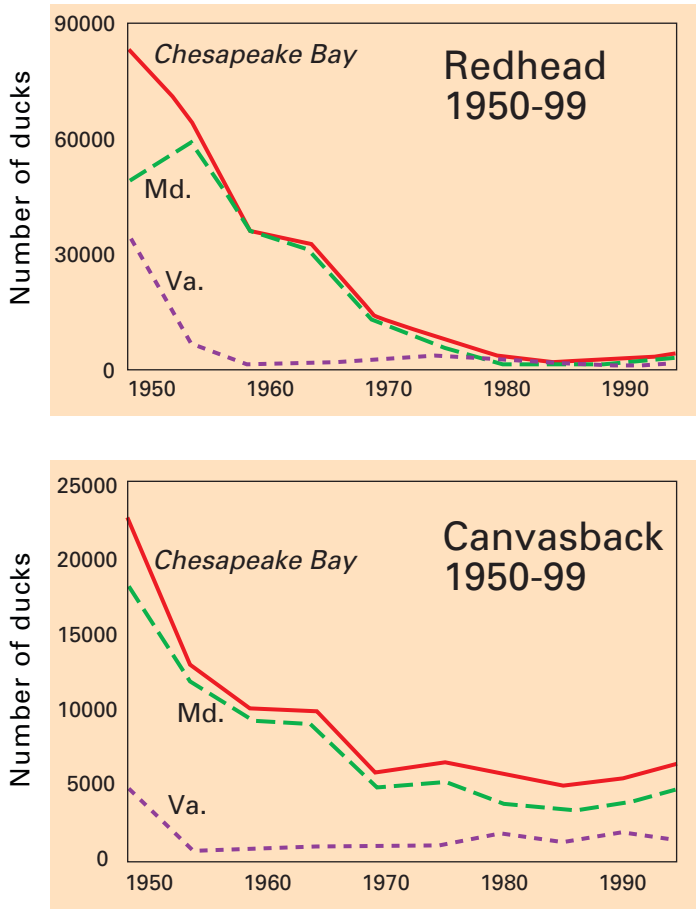


Figure 16. The Chesapeake Bay watershed supports large populations of water birds. However, the population of many species, including redheads and canvasback ducks, has decreased because of the loss of submerged aquatic vegetation (SAV). The redhead population has not recovered, but the canvasback duck has changed its diet from SAV to clams, and its population has stabilized. (From Perry and Deller, 1995.)

Effects of Habitat Loss and Contaminants on Water Birds

The Chesapeake Bay watershed provides critical habitat for migratory birds, but changes in habitat, including decline of SAV and wetlands and the presence of contaminants, have affected bird populations in the region. For example, the loss of SAV has caused changes in duck populations and their food sources. Redhead ducks, which depend on SAV for food, declined from more than 80,000 in 1950 to less than 1,000 by 1980, where the population level remains today (fig. 16). Other species, such as canvasbacks, have changed from SAV to clams and other invertebrates as a food source. Their populations declined during the 1950's to 1970's but have stabilized as they adapted to a different food source (Perry and Deller, 1995).

The USGS is undertaking stable-isotope-ratio studies to understand these, and other food-web linkages, in the bay ecosystem (fig. 17). The results of these studies will help define food sources for both fish and water birds in the bay. This information is needed to develop and revise management and conservation approaches for these valuable resources.

In cooperation with the U.S. Fish and Wildlife Service, the USGS is also addressing the effect of contaminants on bird populations in the bay. Black-crowned night herons and osprey are being studied in three toxics regions of concern (Baltimore Harbor, Anacostia River, and Elizabeth River) to determine if contaminant exposure is resulting in reproductive impairment. Initial results suggest that concentrations of pesticides and their byproducts are below thresholds associated with adverse reproductive effects for black-crowned night herons (Rattner and others, 2001). This work is also part of a larger effort to examine the condition of terrestrial vertebrates in Atlantic Coast estuaries through development of a Contaminant Exposure and Effects—Terrestrial Vertebrates database.

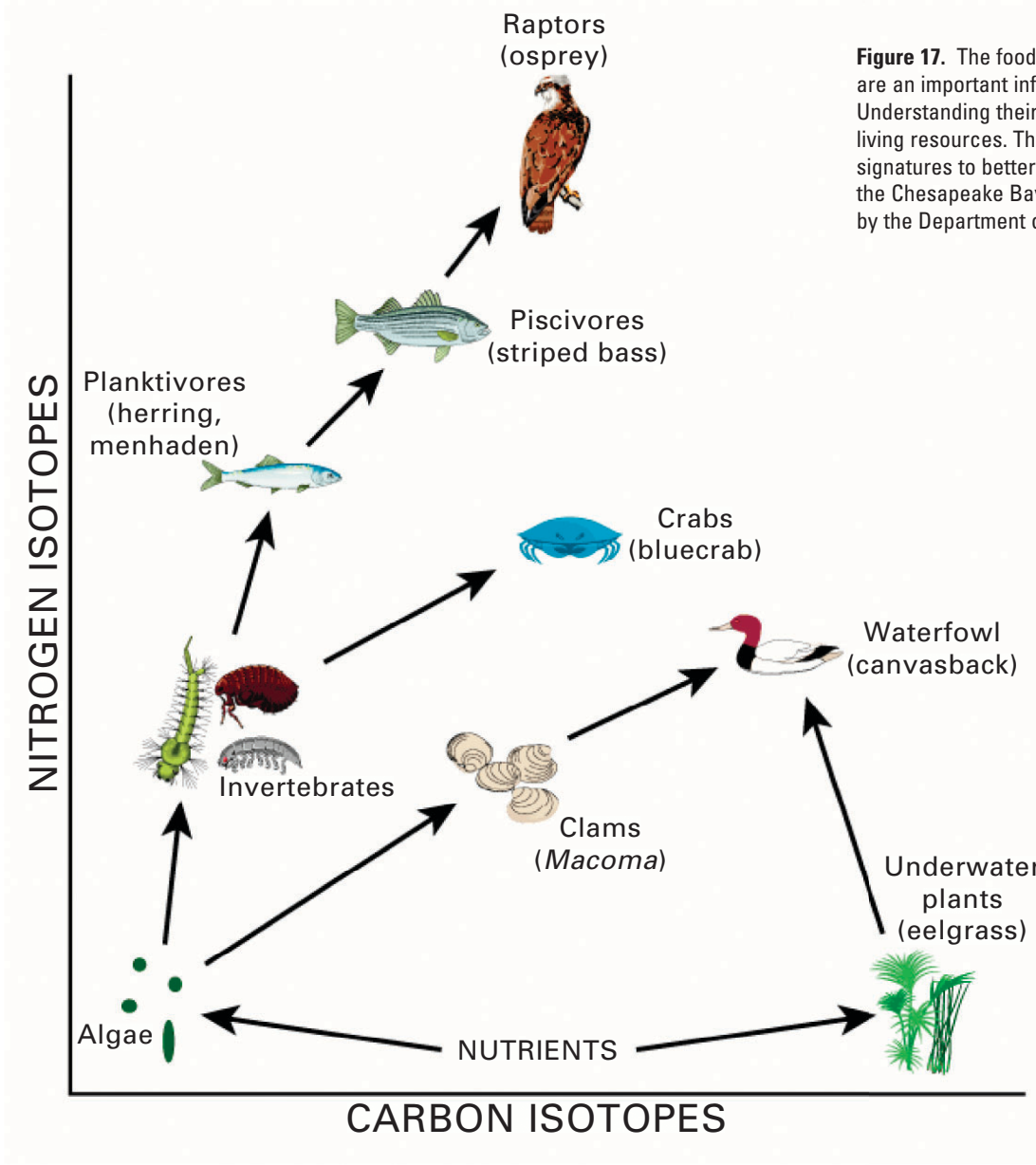


Figure 17. The food web of the Chesapeake Bay ecosystem is complex. Nutrients are an important influence on algae and plants that form the base of the food web. Understanding their relation to water birds, crabs, and fish is critical to protect these living resources. The U.S. Geological Survey is using carbon and nitrogen isotope signatures to better define the food-web relations. This information will be used by the Chesapeake Bay Program to help develop management plans for fisheries and by the Department of Interior to help the conservation of water birds

Osprey.

Figure 18. *Pfiesteria* caused fish kills in the Chesapeake Bay during the late 1990's and was a human-health concern. The U.S. Geological Survey was able to document that the lesions on the fish were related to a fungus. A collaborative study with the Virginia institute of Marine Science will evaluate the role of sublethal exposures to the *Pfiesteria* toxin as a predisposing factor for making fish more susceptible to the fungal infection. Knowing the cause of the lesions and the interaction with *Pfiesteria* is important in understanding fish health problems and making prudent ecosystem management decisions.

Causes of Fish Lesions and Factors Affecting Fish Health

Fisheries are one of the most important living resources of the Chesapeake Bay. Environmental influences related to water quality, contaminants, and food sources affect all stages of fish development and adult health. Additionally, fish kills, fish lesions, and fish disease continue to affect fish development and populations. Fish kills are often caused by low dissolved oxygen, which is related to increased nutrient loading and stratification of the bay waters. However, more study is needed to understand fish health problems, particularly in the context of the whole system—host, pathogen (toxicant), and environment—to make prudent management decisions and to predict when and where problems may develop.

In 1997 and 1998, fish kills and lesions discovered on menhaden (fig. 18), an important species of fish in the bay, were attributed to *Pfiesteria*. Although toxic *Pfiesteria* has not been found in Chesapeake Bay tributaries since 1998, this organism and other harmful algal blooms can have serious effects on natural resources and human health. The State of Maryland established criteria for river closure, using fish lesions as an indicator of *Pfiesteria*. Further study of the menhaden lesions by USGS scientists revealed the presence of a fungus (Blazer and others, 1999). The fungus was identical to a fungal pathogen that causes significant losses of freshwater and estuarine fishes throughout the Indo-Pacific (Australia, Japan, Thailand, India). The fungal pathogen was cultured by using specialized methods developed in these countries, and tests verified that the organism causing the menhaden lesions was *Aphanomyces invadans* (Blazer and others, 1999 and in press). In a collaborative study between the USGS and the Virginia Institute of Marine Science, lesions have been successfully reproduced in laboratory-held menhaden by exposing fish to the fungus. The study will compare the histological effects of *Pfiesteria* toxicity to those observed in wild menhaden and will evaluate the role of sublethal exposures to the *Pfiesteria* toxin as a predisposing factor for making fish more susceptible to the fungal infections.

Environmental factors, such as salinity, clearly influence the presence and growth of the fungal pathogen, as well as the disease resistance of the fish. For example, some species of *Aphanomyces* continue to grow in the lab at salinities of 20 parts per thousand (ppt) or higher, while *A. invadans* does not grow well above 10 ppt. This finding correlates well with field observations. In 1998 and 2000, salinities in the Pocomoke and Wicomico Rivers were below 10 ppt, and menhaden with fungal lesions were observed. In 1999, a drier year, salinities were above 10 ppt, and menhaden with fungal lesions were not found (Blazer and others, 1999 and in press).

Lesions on menhaden are not the only fish health problems that have been reported in recent years. Mycobacteria cause bacterial skin lesions in striped bass and are also a potential human pathogen. Studies by USGS scientists and collaborators are evaluating the infectivity of a variety of pathogens, determining predisposing factors to infection, and studying the immune response of fish. Many factors such as low dissolved oxygen, low pH, and various contaminants such as copper, arsenic, herbicides, and antibiotics directly affect fungal, bacterial, and parasitic pathogens and change the susceptibility of the fish host through immunosuppression. Methods are being developed by the USGS to assess the overall fish health in the Chesapeake Bay.

Delivering Information to USGS Customers

The resource managers and scientists in the CBP have been the primary audience for USGS Chesapeake Bay scientific efforts. The CBP involves a wide variety of Federal (more than 25 agencies), State (6 States and the District of Columbia), and local customers and partners. Other audiences are the USGS National Programs that support scientific investigations, the Department of the Interior (DOI), Congress, professional organizations, and the general public. The USGS has worked aggressively to reach these audiences through active participation in CBP technical subcommittees (fig. 19) and workshops; preparation of Fact Sheets, reports, and journal articles; briefings of USGS, DOI, and Congressional staffers; and provision of press releases to the media.

The CBP in the early 1990's sought to improve information access to the science community and began development of the Chesapeake Information Management System (CIMS). The system depends on participants to supply high-quality data and to make their information accessible through the World Wide Web (WWW) . The CBP is implementing CIMS through a series of memoranda with agencies involved with the restoration effort. The USGS in 1998 became the first Federal agency to sign a CIMS memorandum and created a WWW site to provide information and reports. Both the USGS site (http://chesapeake.usgs.gov) and the CBP site (http://www.chesapeakebay.net) provide information about the bay and its watershed.

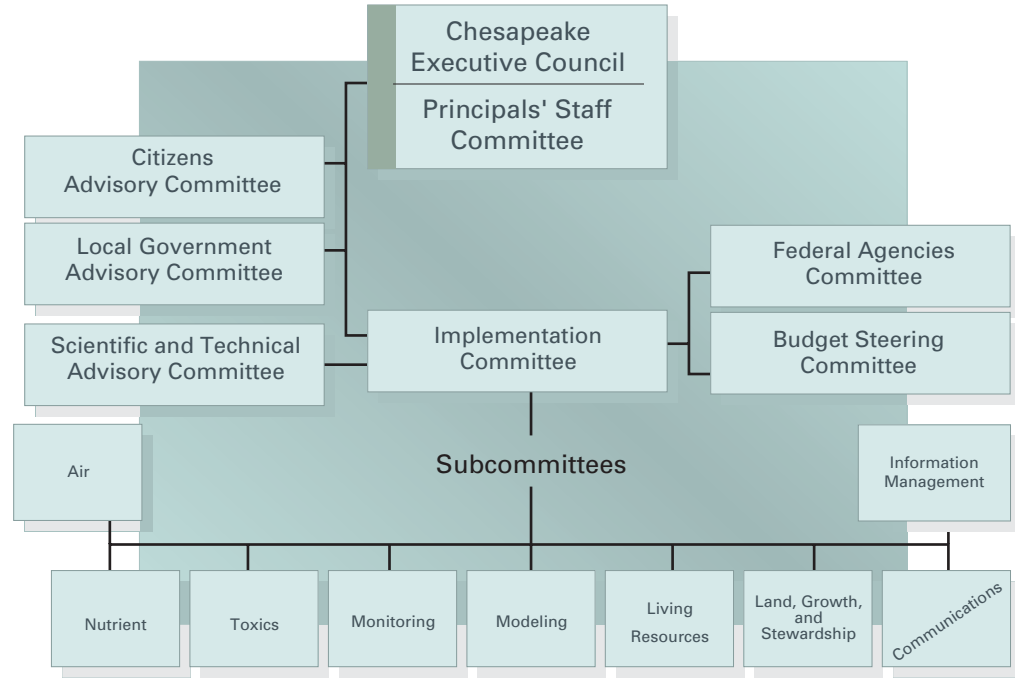


Figure 19. The U.S. Geological Survey (USGS) has representatives on all of the technical subcommitteess of the Chesapeake Bay Program. The scientific findings of the USGS and other agencies are used to formulate restoration strategies and evaluate the effectiveness of those measures. The Chesapeake Executive Council used the information to set restoration goals for the next decade in the Chesapeake 2000 agreement.

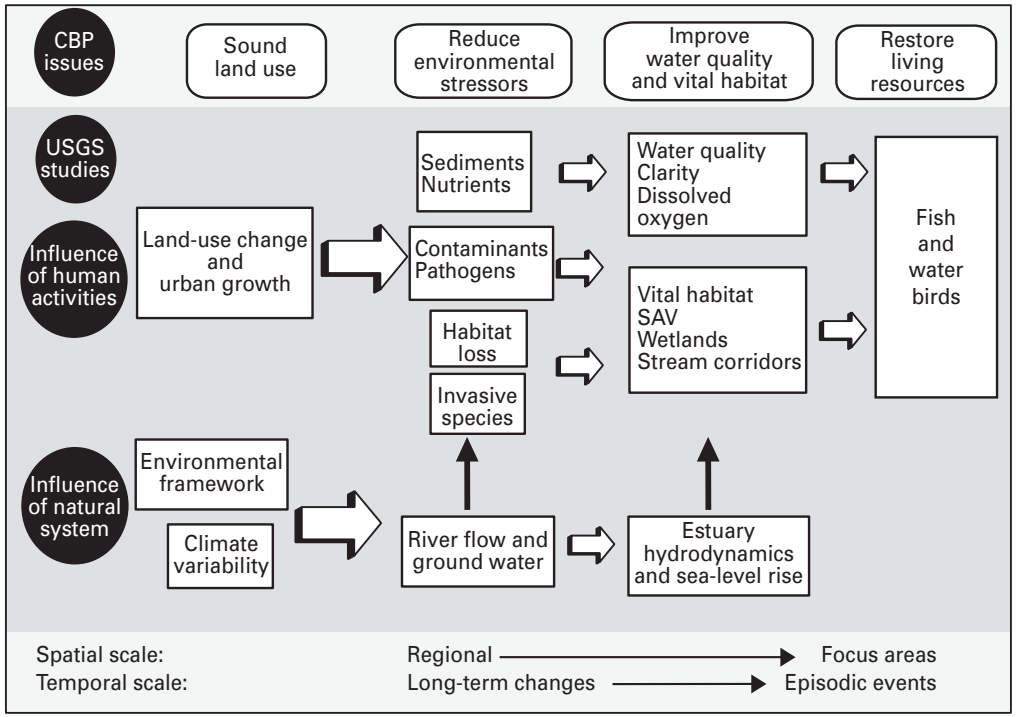


Figure 20. The Chesapeake Bay Program (CBP) is working to implement sound land-use practices to reduce pollutants and habitat loss in the bay and its watershed. These actions are aimed at improving water quality and vital habitat to support living resources. The U.S. Geological Survey (USGS) is taking a multidisciplinary approach to provide science to support the restoration of this complex ecosystem.

Meeting the Needs of Chesapeake 2000

Revised Goals of the USGS Chesapeake Bay Science Program

The USGS revised its overall objective and associated scientific goals to support the expanded technical needs of Chesapeake 2000 and DOI partners. The overall objective of the USGS Chesapeake Bay Science Program is to provide resource managers with information needed to understand the complex relation between the human-induced influences (population growth, land-use change, and restoration efforts) and natural controls (climate variability and watershed characteristics) on water quality, vital habitats, and living resources in the bay and its watershed (fig. 20). Results from six science goals will enhance the information needed and improve the management models used to plan restoration strategies and help evaluate whether the strategies are effective. USGS scientific efforts will include regional studies of the entire bay watershed and several "focus areas" (fig. 21). The focus areas include the Lower Eastern Shore/Pocomoke Basin, Upper Bay/Lower Susquehanna, and Potomac River and estuary. The revised USGS science goals are listed in table 2 and described as follows.

Collecting water samples from the Rappahannock River.

Table 2. Future U.S. Geological Survey (USGS) science goals and their relation to Chesapeake 2000 information needs.

USGS Chesapeake Bay science goals	Chesapeake 2000 information needs
Improve watershed and land-use data to understand changes in water quality and living resources.	The Chesapeake Bay Program (CBP) needs improved land-cover and land-use data to refine watershed-management models and explain water-quality and living-resource conditions.
Understand the impact of sediment on water clarity and biota.	The bay was listed as an "impaired water body" under the Clean Water Act because of poor water clarity, which is degrading submerged aquatic vegetation (SAV). The CBP needs information on the sources of sediment affecting water clarity so that sediment-reduction measures can be formulated and improved water-clarity standards met by 2010. The improvement of SAV must also be evaluated.
Enhance the prediction and monitoring of nutrient delivery to the bay.	Nutrient sources in the watershed must be further reduced to meet new dissolved-oxygen standards for the bay by 2010. Enhanced information is needed to determine which nutrient-source reductions will result in the greatest benefit to the bay and its watershed.
Assess the occurrence of toxic constituents and emerging contaminants.	CBP has the goal of a bay free of toxics. Information is needed on the nonpoint source occurrence of contaminants and emerging contaminants in the watershed and in ground water and the effects on living resources.
Assess the factors affecting the health of fish and water birds.	Restoration of living resources and vital habitat is the highest priority of Chesapeake 2000. Also, Department of Interior is developing conservation measures to protect water birds in the Atlantic Flyway. Information is needed on the effects of land use, water-quality changes, and climate variability on fish, water birds, and other living resources in the bay and its watershed.
Disseminate information and enhance decision-support tools.	CBP needs scientific information integrated through the Chesapeake Information Management System, enhancement of predictive models and decision-support systems, and interaction of scientists and resource managers on subcommittees and work groups.

Subdivision growth near Laurel, Md.

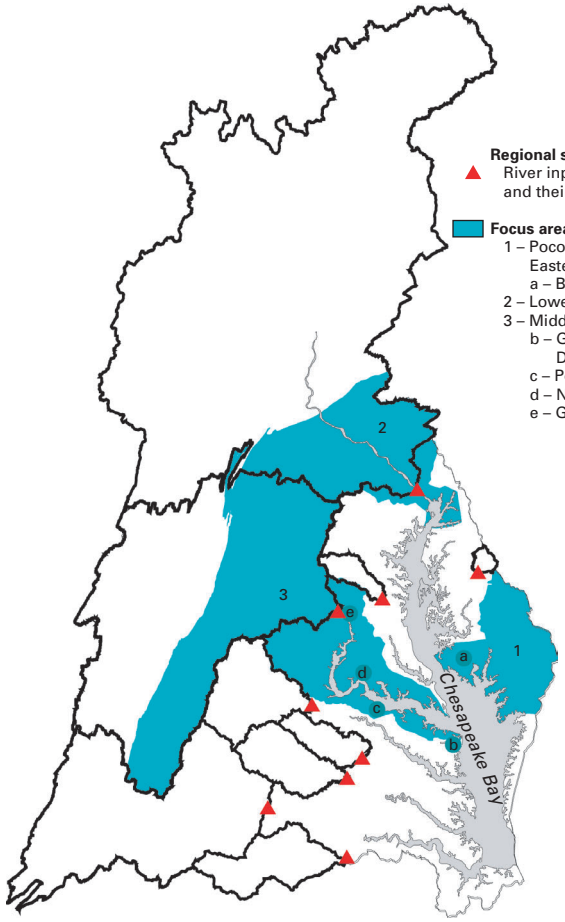


Figure 21. The U.S. Geological Survey is conducting regional studies of the entire Chesapeake Bay watershed and coordinating multiple disciplines in three focus areas. The focus areas include areas of high nutrients, sediments, and toxics due to agricultural, suburban, and urban land use. The western extent of the Potomac and Susquehanna focus areas corresponds to the Great Valley, which is primarily an agricultural region.

Improve watershed and land-use data to understand changes in water quality and living resources.—Land-use change is the primary factor causing water-quality and habitat degradation in the bay and its watershed. Human populations and associated urban areas are expected to grow to 18 million people by 2020 in the bay watershed. There is a need for enhanced information to explain changes in water quality, habitat, and living resources and improve management models and decision-support systems. The USGS will help meet this need by—

- Documenting the sediment, nutrient, and toxic sources associated with urban, suburban, and agricultural lands and compiling information on watershed characteristics that affect the movement of these pollutants.
- Providing an assessment of historical land-use changes to explain changes in water quality, living resources, and associated habitat.
- Applying the information to improve management models.

Understand the impact of sediment on water clarity and biota.—The bay was listed as an "impaired water body" under the Clean Water Act because of poor water clarity. Submerged aquatic vegetation has declined drastically over the past 30 years primarily due to poor water clarity, caused by excess sediment and nutrients. While nutrient sources and transport have been studied since the 1980's, little is known about sediment sources and delivery to the bay. The CBP needs information on the sources of sediment affecting water clarity so that sediment-reduction measures can be formulated and water clarity improved by 2010. Additionally, an assessment is needed to determine whether SAV species are recovering, based on anticipated improvements in water clarity. The USGS will help provide information through—

- Investigating the sources, transport, delivery, and deposition of sediment to the bay.
- Assessing the relation of the sediment and nutrient enrichment to water clarity, submerged aquatic vegetation, and other biota in shallow habitats.
- Documenting the factors affecting the presence of SAV species and any improvements due to the new water-clarity standards.
- Improving predictive models, monitoring, and decision-support systems to help States develop and evaluate the effectiveness of sediment-reduction strategies.

Enhance the prediction and monitoring of nutrient delivery to the bay.—The bay was also listed as an "impaired water body" under the Clean Water Act because of its low dissolved oxygen, which has killed fish and other organisms. Nutrient sources in the watershed must be further reduced to meet new dissolved-oxygen standards by 2010. Enhanced predictive tools are needed to simulate the relation between nutrient sources and delivery to the bay, monitoring must be expanded to document and evaluate water-quality improvement, and studies conducted to understand the processes affecting nutrient delivery to the bay. The USGS will help meet these needs by—

- Partnering with the CBP to refine the Chesapeake Bay Watershed Model (Phase 5) to improve simulation of nutrient sources and their delivery to the bay.
- Linking information on ground-water discharge, loads, and residence times to improve simulation of nutrient delivery to streams in the watershed model.
- Developing a watershed-monitoring network to document improvements in water quality and to enhance monitoring and trends analysis of nutrients in the watershed.
- Conducting investigations of stream nutrient dynamics to determine their affect on biologic communities.

Assess the occurrence of toxic constituents and emerging contaminants.—As part of Chesapeake 2000, the CBP has developed a strategy for toxics that will eliminate the impact of toxic substances on the living resources of the bay and on human health. Technical information needs include (1) documenting the contaminant sources, loads, and impacts of animal agriculture, pesticide use, and ground water and (2) understanding the potential for contaminants to adversely affect impacts on aquatic-dependent wildlife in the bay and its watershed. The USGS efforts in these areas will include—

- Enhancing information on occurrence and impact of emerging contaminants.
- Collecting data on the contaminant concentrations in both surface and ground water associated with different types of land use in areas of the Potomac River basin and the Delmarva Peninsula.
- Understanding the impact of contaminants and other environmental stressors on the health of fish and water birds (see next science goal).

Assess the factors affecting the health of fish and water birds.—Restoration of living resources (including

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oysters, crabs, and fish) and their associated habitat is the highest priority of Chesapeake 2000. Also, the Department of Interior is developing conservation measures to protect water birds in the Atlantic Flyway. To develop the strategies to conserve and restore the ecosystem, scientific information is needed to understand the complex relation of living resources and associated habitats to environmental factors in the bay and its watershed. The USGS will help meet this need through—

- Investigating the affect of endocrine-disrupting chemicals on fish egg quality and survival.
- Assessing the factors affecting the health of adult fish, including the occurrence of fish lesions.
- Understanding the effect of contaminants, habitat loss, and food-web changes on water bird populations.

Disseminate information and enhance decision-support tools.—The primary audience for the USGS Chesapeake Bay Science Program is the CBP. The CBP requires USGS research, monitoring, and predictive models of the Chesapeake Bay and its watershed to help formulate and evaluate restoration strategies. USGS Chesapeake Bay science information also has critical relevance for the restoration of ecosystems throughout the United States. Therefore, multiple approaches and associated infrastructures are needed to provide information not only to the CBP but also to other audiences, including scientific organizations, representatives of Congress, the Department of the Interior, and groups within the USGS. This will be done by—

- Developing decision-support tools through the integration of predictive model results, monitoring data, and ancillary information. The predictive models will include (1) joint USGS-CBP enhancement of the bay watershed model that simulates nutrient and sediment delivery to the bay and (2) the USGS SPARROW models.
- Disseminating decision-support information through development of an WWW-based GIS system and integration with CBP CIMS delivery approaches (such as watershed profiles).
- Increasing participation in CBP subcommittees and workgroups to enhance the exchange of information.

Role of USGS National Programs in Supporting Chesapeake 2000 Goals

The success of the USGS Chesapeake Bay Science Program in supporting Chesapeake 2000 goals depends on the involvement of USGS National Programs and their respective field operations and scientists. The USGS has worked to integrate the efforts of different programs, their respective program objectives, and the needs of the Chesapeake Bay restoration effort. Some of the USGS National Programs and their roles in the providing science for the bay restoration effort are summarized in table 3.

Table 3. U.S. Geological Survey (USGS) programs supporting the Chesapeake Bay restoration efforts.

USGS program	Role in support of bay restoration
Biology program areas related to fisheries and aquatic resources, contaminants, wildlife, invasive species, and ecosystems.	Research vital habitats, including submerged aquatic vegetation, (SAV), wetlands, invasive species, and selected living resources such as fisheries and water birds.
Coastal and Marine Geology Program.	Research sediment sources and dynamics affecting water clarity and habitats.
National Cooperative Geologic Mapping Program.	Create maps of geologic and geomorphic characteristics of sediment transport and deposition.
Earth Surface Dynamics Program.	Research the effects of land-cover change and climate variability on sediment deposition and subsequent effects on water clarity and SAV and other biological communities.
Landscape Analysis Program.	Research to document relation of land-cover and land-use changes to changes in water quality and living resources.
Hydrologic Networks and Analysis Program.	Quantify the amount of stream flow, nutrients, and sediment entering Chesapeake Bay.
Hydrology Research and Development Program.	Study the relation of sediment sources, transport, and delivery to shallow-water habitats for SAV. Research characterizing abundance and extent of SAV coverage in relation to sediment, seasonal water quality, and hydroclimatology. Research nutrient cycling in surface-water and ground-water systems.
Cooperative Water Program.	Enhance surface-water monitoring efforts to document sediment and nutrient loads, trend analysis, factors affecting loads and trends, and predictive models.
National Water-Quality Assessment (NAWQA) Program.	Work with Potomac/Delmarva study unit to understand nutrient and contaminant processes.
Global Climate Change Program.	Research the effect of sea-level rise on habitat.
Regional place-based studies.	Support all USGS Chesapeake Bay science goals by integrating scientific investigations and supplying information to Chesapeake Bay Program.

USGS Partnerships

The USGS interacts and collaborates with many Federal, State, and academic partners in the Chesapeake Bay Program and related investigations. Major partners and areas of interaction include—

- The U.S. Department of Interior (DOI). The USGS collaborates with both the U.S. Fish and Wildlife Service and the National Park Service to study factors affecting water bird populations and their habitats on DOI lands in the bay watershed.
- The U.S. Environmental Protection Agency (USEPA). The USEPA is the Federal lead for the bay restoration efforts, and the USGS works closely with the USEPA on watershed model enhancement, monitoring, and delivery of scientific information to State and local governments.
- The U.S. Department of Agriculture (USDA). Interaction with the USDA is critical to apply nutrient-source data to watershed models and explain water-quality conditions.
- The National Aeronautics and Space Administration (NASA). The USGS works with NASA to collect and intepret remote-sensing information to identify areas of poor water clarity in the bay.
- The Maryland Department of Natural Resources and the Virginia Department of Environmental Quality. Collection of nutrient and sediment information from the major rivers draining into the bay is a cooperative project between these State agencies and the USGS.
- The Maryland Geological Survey (MGS). The MGS and the USGS work closely to monitor (1) stream flow in the watershed and (2) sediment in the bay.
- The Susquehanna River Basin Commission (SRBC). Monitoring nutrients and sediment in the Susquehanna basin and their impact on the Chesapeake Bay has been a joint effort of the SRBC and the USGS.
- The Maryland Department of the Environment, the Interstate Commission of the Potomac River Basin, and the Virginia Department of Conservation and Recreation. Refinement of the Chesapeake Bay watershed model is a cooperative project among these agencies, the USEPA, and the USGS.
- Virginia Institute of Marine Sciences (VIMS). The USGS and VIMS are studying the factors that affect fish health in the bay.
- George Mason University (GMU). The USGS and GMU are working to determine the effect of antibiotics on portions of the bay ecosystem.

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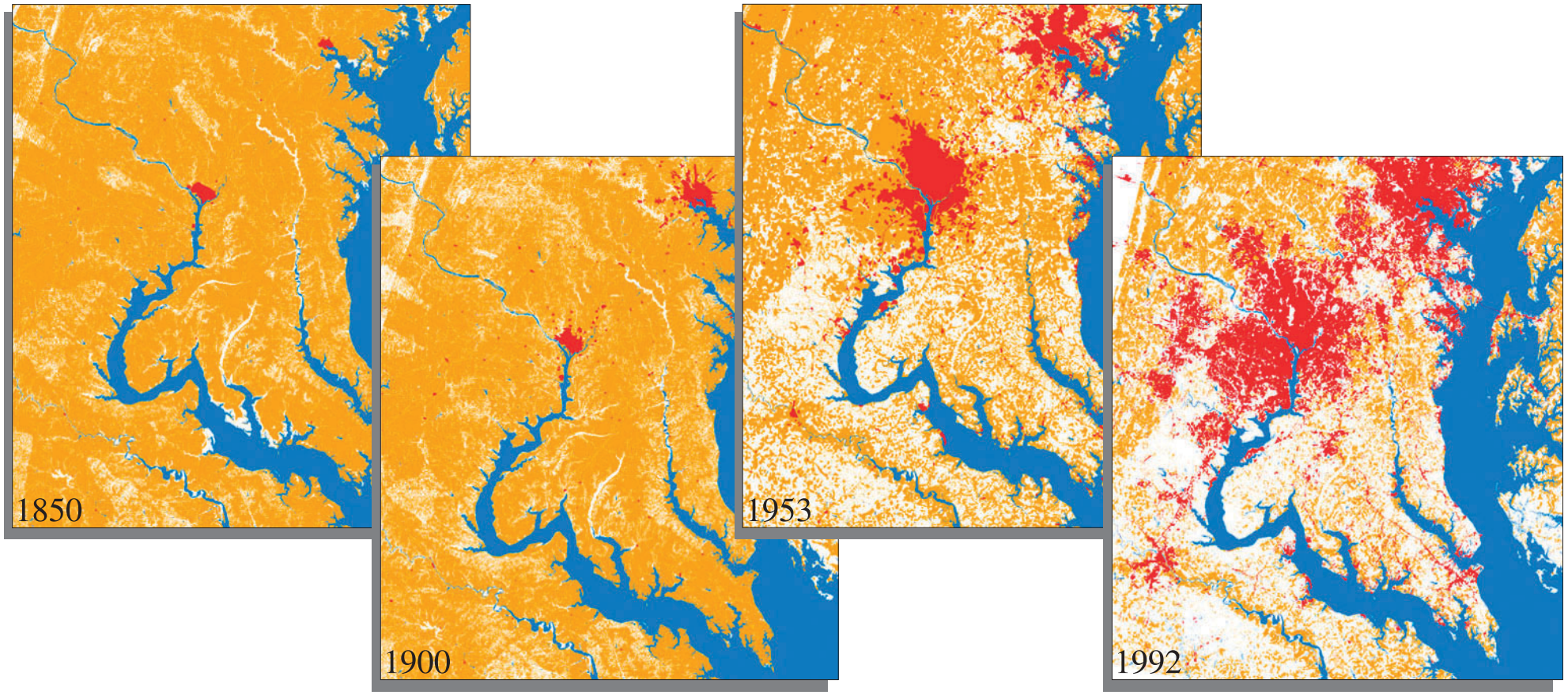

This series of maps compares changes in urban (red) and agricultural (gold) lands in the Patuxent River watershed over the past 140 years. Agriculture was at its peak in the mid- to late-1800's in this area.