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Conservation Effects
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(CEAP)

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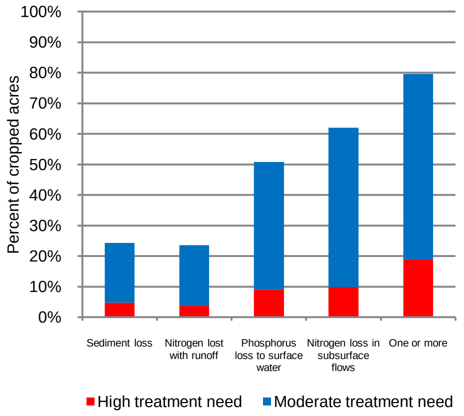
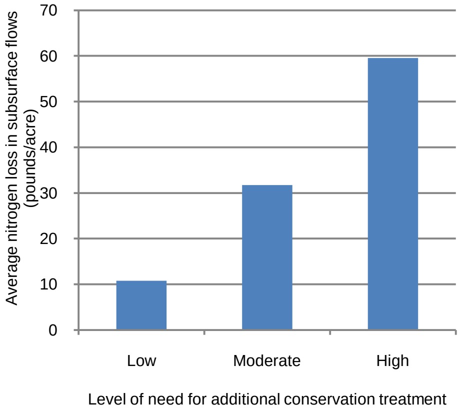
Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Chesapeake Bay Region





Cover photos are by (clockwise from top left) **Tim McCabe, Bob Nichols, Lynn Betts, Tim McCabe,** USDA Natural Resources Conservation Service**.**

CEAP—Strengthening the science base for natural resource conservation

The Conservation Effects Assessment Project (CEAP) was initiated by USDA's Natural Resources Conservation Service (NRCS), Agricultural Research Service (ARS), and Cooperative State Research, Education, and Extension Service (CSREES—now National Institute of Food and Agriculture [NIFA]) in response to a general call for better accountability of how society would benefit from the 2002 Farm Bill's substantial increase in conservation program funding (Mausbach and Dedrick 2004). The original goals of CEAP were to estimate conservation benefits for reporting at the national and regional levels and to establish the scientific understanding of the effects and benefits of conservation practices at the watershed scale. As CEAP evolved, the scope was expanded to provide research and assessment on how to best use conservation practices in managing agricultural landscapes to protect and enhance environmental quality.

CEAP activities are organized into three interconnected efforts:

- *Bibliographies, literature reviews, and scientific workshops* to establish what is known about the environmental effects of conservation practices at the field and watershed scale.

- *National and regional assessments* to estimate the environmental effects and benefits of conservation practices on the landscape and to estimate conservation treatment needs. The four components of the national and regional assessment effort are *Cropland*; *Wetlands*; *Grazing lands*, including rangeland, pastureland, and grazed forest land; and *Wildlife*.

- *Watershed studies* to provide in-depth quantification of water quality and soil quality impacts of conservation practices at the local level and to provide insight on what practices are the most effective and where they are needed within a watershed to achieve environmental goals.

Research and assessment efforts were designed to estimate the effects and benefits of conservation practices through a mix of research, data collection, model development, and model application. Duriancik et al. (2008) summarize the accomplishments of CEAP through 2007. A vision for how CEAP can contribute to better and more effective delivery of conservation programs in the years ahead is addressed in Maresch, Walbridge, and Kugler (2008). Additional information on the scope of the project can be found at http://www.nrcs.usda.gov/technical/nri/ceap/.

This report was prepared by the Conservation Effects Assessment Project (CEAP) Cropland Modeling Team and published by the United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). The modeling team consists of scientists and analysts from NRCS, the Agricultural Research Service (ARS), Texas AgriLife Research, and the University of Massachusetts.

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Foreword

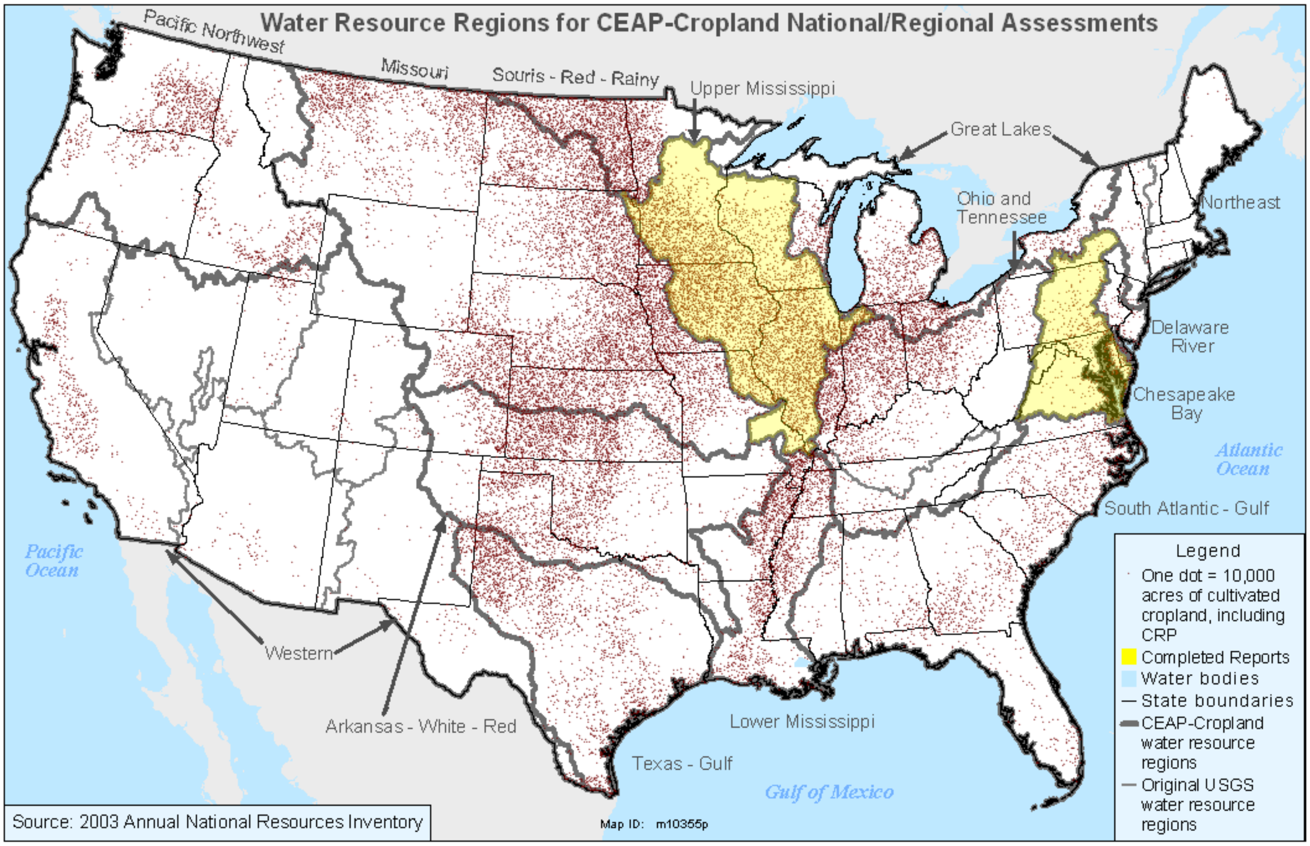
The United States Department of Agriculture has a rich tradition of working with farmers and ranchers to enhance agricultural productivity and environmental protection. Conservation pioneer Hugh Hammond Bennett worked tirelessly to establish a nationwide Soil Conservation Service along with a system of Soil and Water Conservation Districts. The purpose of these entities, now as then, is to work with farmers and ranchers and help them plan, select, and apply conservation practices to enable their operations to produce food, forage, and fiber while conserving the Nation's soil and water resources.

USDA conservation programs are voluntary. Many provide financial assistance to producers to help encourage adoption of conservation practices. Others provide technical assistance to design and install conservation practices consistent with the goals of the operation and the soil, climatic, and hydrologic setting. By participating in USDA conservation programs, producers are able to—

- install structural practices such as riparian buffers, grass filter strips, terraces, grassed waterways, and contour farming to reduce erosion, sedimentation, and nutrients leaving the field;
- adopt conservation systems and practices such as conservation tillage, comprehensive nutrient management, integrated pest management, and irrigation water management to conserve resources and maintain the long-term productivity of crop and pasture land; and
- retire land too fragile for continued agricultural production by planting and maintaining on them grasses, trees, or wetland vegetation.

Once soil conservation became a national priority, assessing the effectiveness of conservation practices has been important. Over the past several decades, the relationship between crop production and the landscape in which it occurs has become better understood in terms of the impact on sustainable agricultural productivity and the impact of agricultural production on other ecosystem services that the landscape has potential to generate. Accordingly, the objectives of USDA conservation policy have expanded along with the development of conservation practices to achieve them.

This report on the Chesapeake Bay region is the second in a series of regional reports that continues the tradition within USDA of assessing the status, condition, and trends of natural resources to determine how to improve conservation programs to best meet the Nation's needs. These reports use a sampling and modeling approach to quantify the environmental benefits that farmers and conservation programs are currently providing to society, and explore prospects for attaining additional benefits with further conservation treatment. Subsequent reports on cultivated cropland will be prepared for regions shown in the following map.



Source: 2003 Annual National Resources Inventory

Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Chesapeake Bay Region

Contents

Page

Key Findings 6

Executive Summary 6

Chapter 1: Land Use and Agriculture in the Chesapeake Bay Region
Land Use 13
Agriculture 13
Watersheds 16

Chapter 2: Overview of Sampling and Modeling Approach
Scope of Study 17
Sampling and Modeling Approach 17
The NRI and the CEAP Sample 18
The NRI-CEAP Cropland Survey 19
Simulating the Effects of Weather 19

Chapter 3: Evaluation of Conservation Practice Use—the Baseline Conservation Condition
Historical Context for Conservation Practice Use 22
Summary of Practice Use 22
Structural Conservation Practices 23
Residue and Tillage Management Practices 25
Conservation Crop Rotation 28
Cover Crops 28
Irrigation Management Practices 28
Nutrient Management Practices 29
Pesticide Management Practices 34
Conservation Cover Establishment 36

Chapter 4: Onsite (Field-Level) Effects of Conservation Practices
The Field-Level Cropland Model—APEX 37
Simulating the No-Practice Scenario 38
Effects of Practices on Fate and Transport of Water 43
Effects of Practices on Wind Erosion 46
Effects of Practices on Water Erosion and Sediment Loss 47
Effects of Practices on Soil Organic Carbon 51
Effects of Practices on Nitrogen Loss 54
Effects of Practices on Phosphorus Loss 61
Effects of Practices on Pesticide Residues and Environmental Risk 65

Chapter 5: Assessment of Conservation Treatment Needs
Conservation Treatment Levels 70
Inherent Vulnerability Factors 73
Evaluation of Conservation Treatment 78

Chapter 6: Assessment of Potential Field-Level Gains from Further Conservation Treatment
Simulation of Additional Water Erosion Control Practices 90
Simulation of Additional Nutrient Management Practices 91
Potential for Field-Level Gains 92

Chapter 7: Offsite Water Quality Effects of Conservation Practices

The National Water Quality Model—HUMUS/SWAT 105
Source Loads and Instream Loads 109
Conservation Practice Effects on Water Quality 112
Assessment of Potential Water Quality Gains from Further Conservation Treatment 128
Summary of Conservation Practice Effects on Water Quality in the Chesapeake Bay Watershed 137

References 141

Appendix A: Estimates of Margins of Error for Selected Acres Estimates 143

Appendix B: Model Simulation Results for the Baseline Conservation Condition for the Four Subregions in the Chesapeake Bay Region 147

Appendix C: Simulation of Full Adoption of Cover Crops in the Chesapeake Bay Region 149

Documentation Reports

There are a series of documentation reports and associated publications by the modeling team posted on the CEAP website at: http://www.nrcs.usda.gov/technical/nri/ceap/Cropland.html. Included are the following reports that provide details on the modeling and databases used in this study:

- The HUMUS/SWAT National Water Quality Modeling System and Databases
- Calibration and Validation of CEAP-HUMUS
- Delivery Ratios Used in CEAP Cropland Modeling
- APEX Model Validation for CEAP
- Pesticide Risk Indicators Used in CEAP Cropland Modeling
- Integrated Pest Management (IPM) Indicator Used in CEAP Cropland Modeling
- NRI-CEAP Cropland Survey Design and Statistical Documentation
- Transforming Survey Data to APEX Model Input Files
- Modeling Structural Conservation Practices for the Cropland Component of the National Conservation Effects Assessment Project
- APEX Model Upgrades, Data Inputs, and Parameter Settings for Use in CEAP Cropland Modeling
- APEX Calibration and Validation Using Research Plots in Tifton, Georgia
- The Agricultural Policy Environmental EXtender (APEX) Model: An Emerging Tool for Landscape and Watershed Environmental Analyses
- The Soil and Water Assessment Tool: Historical Development, Applications, and Future Research Directions
- Historical Development and Applications of the EPIC and APEX Models
- Assumptions and Procedures for Simulating the Natural Vegetation Background Scenario for Cropland
- Manure Loadings Used to Simulate Pastureland and Hayland in CEAP HUMUS/SWAT modeling
- Adjustment of CEAP Cropland Survey Nutrient Application Rates for APEX Modeling

This report was initially drafted in August 2010, and was distributed to about 20 researchers and scientists familiar with the Chesapeake Bay for review and comment. The report was subsequently modified to address reviewers' comments and posted on the Internet for public review and comment in October 2010. One of the suggestions was to add a "what if" simulation on the effects of cover crops. To conduct this analysis, the field-level process model was upgraded with improved modeling routines for winter plant growth. Use of these revised modeling routines resulted in changes to most of the model outcomes, which is why results reported in this final report differ from earlier drafts. While most changes were relatively moderate, the changes in model routines significantly decreased estimates of acres with a high need for additional treatment (critical under-treated acres). Estimates of all under-treated acres, however, were relatively unaffected.

Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Chesapeake Bay Region

Key Findings

The voluntary, incentives-based conservation approach is working. Farmers have made good progress in reducing sediment, nutrient, and pesticide losses from farm fields through conservation practice adoption throughout the Chesapeake Bay region. Most cropland acres have structural or management practices—or both—in place to control erosion. Nearly half the cropland acres are protected by one or more structural practices, such as buffers or terraces. Reduced tillage is used in some form on 88 percent of the cropland. Adoption of conservation practices has reduced edge-of-field sediment loss by 55 percent, losses of nitrogen with surface runoff by 42 percent, losses of nitrogen in subsurface flows by 31 percent, and losses of phosphorus (sediment attached and soluble) by 41 percent.

Opportunities exist to further reduce sediment and nutrient losses from cropland. The assessment of conservation treatment needs presented in this study identifies opportunities to contribute to improved water quality in the Bay. The study found that 19 percent of cropped acres (810,000 acres) have a high level of need for additional conservation treatment. Acres with a high level of need consist of the most vulnerable acres with the least conservation treatment and the highest losses of sediment and nutrients. Model simulations show that adoption of additional conservation practices on these 810,000 acres would, compared to the 2003–06 baseline, further reduce edge-of-field sediment loss by 37 percent, losses of nitrogen with surface runoff by 27 percent, losses of nitrogen in subsurface flows by 20 percent, and losses of phosphorus (sediment-attached and soluble) by 25 percent.

Targeting enhances effectiveness and efficiency. Targeting critical acres significantly improves the effectiveness of conservation practice implementation. Use of additional conservation practices on acres that have a high need for additional treatment—acres most prone to runoff or leaching and with low levels of conservation practice use—can reduce sediment and nutrient per-acre losses by over twice as much as treatment of acres with a low or moderate conservation treatment need.

Comprehensive conservation planning and implementation is essential. The most critical conservation concern related to cropland in the region is the need to reduce nutrient losses from farm fields, especially nitrogen in subsurface flows. Suites of practices that include soil erosion control and comprehensive nutrient management—appropriate rate, form, timing, *and* method of application—are required to simultaneously address soil erosion, nutrient losses in runoff, *and* loss of nitrogen through leaching.

Executive Summary

Overview of the Chesapeake Bay Region

The Chesapeake Bay is the largest estuary in the United States. The Bay is about 200 miles long, and the Bay and its tributaries cover about 4,500 square miles of open water. The Chesapeake Bay watershed covers about 68,500 square miles in parts of six states (Delaware, Maryland, New York, Pennsylvania, Virginia, and West Virginia) and the District of Columbia. Agricultural land makes up less than 30 percent of the area of the watershed (10 percent cultivated cropland and 18 percent grazing land and hayland). Forest land covers about 59 percent and urban land about 8 percent of the region. The balance of the area is in wetlands or is open water.

Agriculture plays an important role in the economy of the Bay Watershed. The 2007 Census of Agriculture reported that there were nearly 84,000 farms in the Chesapeake Bay region and that the value of agricultural sales in 2007 was about $9.5 billion—24 percent from crops and 76 percent from livestock. About 51 percent of Chesapeake Bay region farms primarily raise crops, about 42 percent are primarily livestock operations, and the remaining 7 percent produce a mix of livestock and crops. Most of the farms (74 percent) in 2007 were small operations with less than $50,000 in total farm sales. About 7 percent of the farms had total farm sales greater than $500,000. Forty-three percent of the farms in the Chesapeake Bay region are smaller than 50 acres. Corn, soybeans, and hay are the principal crops grown.

Livestock production in the region is dominated by poultry production, followed by dairy. Livestock operations in the region produced 10 percent of all poultry and egg sales in the United States in 2007, exceeding $3.7 billion in value. Sales of dairy products ranked second in the region at $2.2 billion, representing 7 percent of the U.S. total. Populations of pastured cattle, horses, and ponies are also significant, representing about one-third of the total livestock population in the region in 2007.

Challenges Faced by Agriculture

Cropped acres in the Chesapeake Bay region have a high vulnerability profile compared to other agricultural regions in the country. A comparison of the vulnerability factors in the Upper Mississippi River Basin and Chesapeake Bay watersheds related to the loss of sediment and nutrients from cropped acres reveals that per-acre losses are higher in the Chesapeake Bay region, on average. Compared to the Upper Mississippi River Basin, the Chesapeake Bay region has—

- higher annual precipitation, averaging 8 more inches per year;
- a higher percentage of cropped acres with slopes greater than 2 percent (60 percent compared to 42 percent);
- a higher percentage of cropped acres that are highly erodible land (44 percent compared to 18 percent);
- a higher percentage of cropped acres with soils prone to surface water runoff (23 percent compared to 13 percent);
- a higher percentage of cropped acres with a “high” or “moderately high” soil leaching potential (46 percent compared to 9 percent); and
- a higher percentage of cropped acres with manure applied (38 percent compared to 18 percent).

Because of the higher vulnerability factors, the Chesapeake Bay region has higher per-acre average annual losses of sediment, nitrogen, and phosphorus from fields than does the Upper Mississippi River Basin. For the baseline conservation condition (based on the 2003–06 farmer survey)—

- sediment loss from fields averages 1.2 tons per acre in the Chesapeake Bay region compared to 0.9 ton per acre in the Upper Mississippi River Basin;
- total nitrogen loss from fields averages 50 pounds per acre in the Chesapeake Bay region compared to 40 pounds per acre in the Upper Mississippi River Basin; and
- total phosphorus loss from fields averages 3.8 pounds per acre in the Chesapeake Bay region compared to 3.2 pounds per acre in the Upper Mississippi River Basin.

Overview of Data Collection and Modeling

The focus of the CEAP Chesapeake Bay study is on the 10 percent of the watershed (4.38 million acres) that is cultivated cropland. The study was designed to quantify the effects of conservation practices commonly used on cultivated cropland in the Chesapeake Bay region, evaluate the need for additional conservation treatment in the region, and estimate the potential gains that could be attained with additional conservation treatment.

Simulation models were used to estimate the effects of conservation practices that were in use during the period 2003–06. The National Resources Inventory, a statistical survey of conditions and trends in soil, water, and related resources on U.S. non-Federal land conducted by USDA’s Natural Resources Conservation Service, provides the statistical framework.

Information on farming activities and conservation practices was obtained primarily from a farmer survey conducted as part of the study. The assessment includes not only practices associated with Federal conservation programs but also the conservation efforts of States, independent organizations, and individual landowners and farm operators.

Farmer Survey Summary

A farmer survey obtained information on the extent of conservation practice use in the Chesapeake Bay region for the period 2003–06. The survey results define the “baseline conservation condition.”

- Structural practices for controlling water erosion are in use on 46 percent of cropped acres, including 63 percent of the highly erodible land.
- About 88 percent of the acres have a conservation tillage system in use including no-till (48 percent) or mulch till (40 percent).
- Producers use residue and tillage management practices, structural practices, or both, on nearly all (96 percent) cropped acres in the region.
- Appropriate rates of nitrogen application are in use on about 35 percent of the acres receiving nitrogen (including manure) for all crops in the rotation.
- Appropriate timing of nitrogen application is in use on about 54 percent of the acres receiving nitrogen (including manure) for all crops in the rotation.

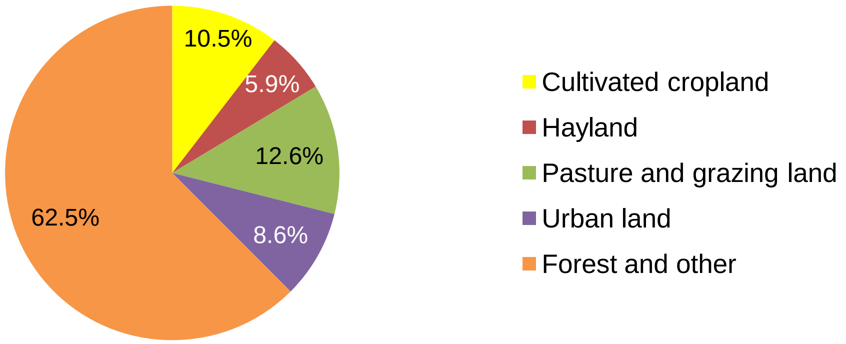
- Good nitrogen management practices (rate, timing and method) are in use on about 13 percent of the acres receiving nitrogen (including manure) for all crops during every year of production.
- Good phosphorus management practices (rate, timing, *and* method) are in use on 17 percent of the acres receiving phosphorus (including manure) for all crops during every year of production.
- While most acres have evidence of some nitrogen or phosphorus management, there is an opportunity to enhance existing nutrient management practices on most acres, especially those receiving manure.
- Land in long-term conserving cover, as represented by enrollment in the CRP General Signup, consists of about 100,000 acres in the region (2 percent of cultivated cropland acres), of which 67 percent is highly erodible land.

Since 2003–06, when the farmer survey was conducted, the six States in the Chesapeake Bay watershed have continued to work with farmers to enhance conservation practice adoption. In Maryland, for example, the State offered expanded incentive payments for the planting of cover crops starting in the 2008–09 growing season. State and Federal programs in the region have expanded incentives for manure incorporation, use of variable rate applications, side-dressing of nutrients, and other production techniques targeted at reducing losses of nutrients from farm fields. In addition, the 2008 Farm Bill increased Federal resources targeted to addressing nutrients and sediment in the Chesapeake Bay watershed. As a result, cover crops and nutrient management practices are probably in wider use within the watershed than the CEAP survey shows for 2003–06.

Distribution of Land Uses and Sources of Sediment and Nutrients

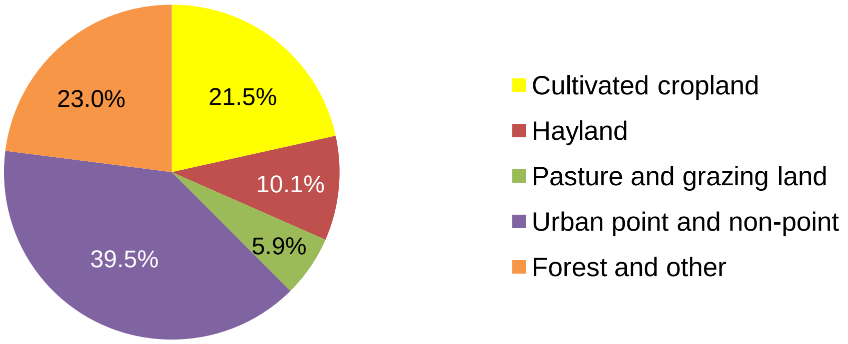
Land use. The majority (59 percent) of the land in the Chesapeake Bay watershed is forested. Pasture and hayland cover 18.5 percent of the watershed, cultivated cropland 10.5 percent, and urban land 8.6 percent. (Another 3.5 percent is in other small land uses, combined with forestland in the figure below.)

Land Use (exclusive of water)



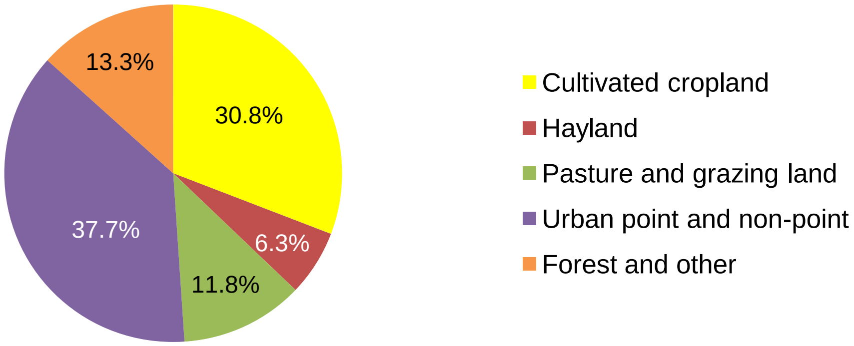
Sediment sources. Urban land is the largest source of sediment delivered to rivers and streams, delivering 39.5 percent of the sediment. Another 23 percent comes from forest land and other minor land uses, and 21.5 percent comes from cultivated cropland. These three land use categories—urban land, forest land, and cultivated cropland—contribute 84 percent of all sediment delivered to rivers and streams in the watershed.

Sediment delivered to rivers and streams



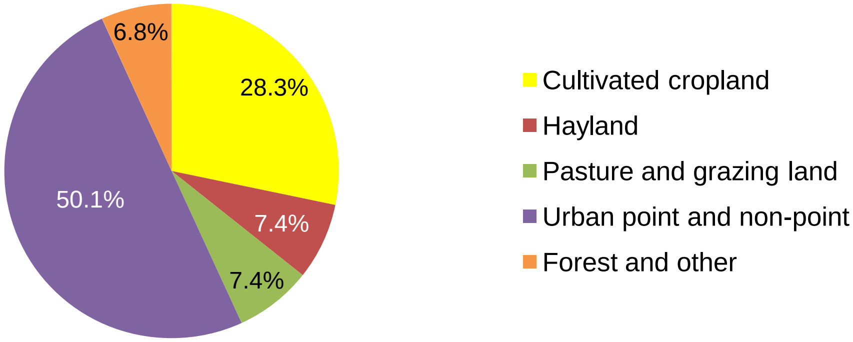
Nitrogen Sources. Urban land is also the largest source of nitrogen delivered to rivers and streams in the watershed, contributing 37.7 percent of the nitrogen. Cultivated cropland contributes 30.8 percent, and forest land and other minor land uses contributes 13.3 percent. Urban areas, forests, and cultivated cropland together account for nearly 82 percent of the nitrogen delivered to rivers and streams in the Chesapeake Bay watershed.

Total nitrogen delivered to rivers and streams



Phosphorus Sources. Over half of the phosphorus delivered to streams and rivers comes from urban land. Cropland contributes 28.3 percent and forest land and other minor land uses contribute 6.8 percent. About 85 percent of total phosphorus delivered to rivers and streams in the watershed are from urban land, cultivated cropland, and forest land.

Total phosphorus delivered to rivers and streams



Contribution on a per acre basis. On a per-acre basis, loadings of sediment and nutrients from urban land and cultivated cropland are disproportionately higher than are loadings from other land uses. The following table summarizes the per-acre sediment and nutrient loadings by major land use. Forest land has the lowest per-acre contribution, while urban areas have the highest per-acre contribution.

Per-acre contributions of sediment and nutrients to rivers and streams in the Chesapeake Bay region, by land use

	Pounds per acre delivered to rivers and streams annually		
Land use	Sediment	Nitrogen	Phosphorus
Cultivated cropland	897	23.1	1.5
Hayland	743	8.3	0.7
Pasture	206	7.4	0.3
Urban	2,011	34.6	3.2
Forest and other	160	1.7	0.1

Conservation Accomplishments

Compared to a model scenario with all conservation practices removed, conservation practices in use during the period 2003–06 were shown to have—

- reduced sediment loss from fields by 55 percent;
- reduced nitrogen lost with surface runoff (attached to sediment and in solution) by 42 percent;
- reduced nitrogen loss in subsurface flows by 31 percent;
- reduced total phosphorus loss from fields by 40 percent;
- reduced pesticide loss from fields to surface water, resulting in a 22 to 24 percent reduction in edge-of-field pesticide risk (all pesticides combined) for humans and aquatic ecosystems; and
- increased the percentage of acres gaining or maintaining soil organic carbon.

The high losses of nitrogen in subsurface flows result from a combination of incomplete nutrient management and the re-routing of surface water runoff to subsurface flows by water erosion control practices on some acres in the region. On 17 percent of the cropped acres, nitrogen losses in subsurface flows increase slightly as a result of conservation practices. Structural erosion control practices, residue management practices, and reduced tillage slow the flow of surface water runoff and allow more of the water to infiltrate into the soil. This re-routing of surface water to subsurface flows not only redirects the soluble nitrogen into subsurface flows but also can extract additional nitrogen from the soil as the water passes through the soil profile.

For land in long-term conserving cover (100,000 acres), soil erosion and sediment loss have been almost completely eliminated. Compared to a cropped condition without conservation practices, average annual total nitrogen loss has been reduced by 88 percent, average annual total phosphorus loss has been reduced by 92 percent, and soil organic carbon has been increased by an average of more than 333 pounds per acre per year.

Potential for Gains Related to Cover Crop Use

About 4 percent of cropped acres used cover crops during 2003–06 time period used to evaluate conservation practices in this study. In recent years, however, the use of cover crops in the Chesapeake Bay region has increased, particularly where State incentive programs have been implemented. To estimate the potential for cover crops to reduce sediment and nutrient loss from fields in this region, a “what if” scenario was created that simulated the use of cover crops on ***all*** cropped acres. Results indicate that a hypothetical full adoption of cover crops in this region would, compared to the baseline conservation in 2003 to 2006—

- further reduce sediment loss by an average of 59 percent;
- further reduce total nitrogen loss (all loss pathways combined) by an average of 19 percent and nitrogen loss in subsurface flows by an average of 31 percent;
- further reduce total phosphorus loss by an average of 32 percent;
- reduce the acres with a high level of treatment need from 19 percent to 11 percent; and
- reduce the acres with a moderate level of treatment need from 61 percent to 42 percent.

Conservation Treatment Needs

Evaluation of the baseline conservation condition. The adequacy of conservation practices in use for the period 2003–06 in the Chesapeake Bay region was evaluated to identify remaining conservation treatment needs. *Under-treated acres are those where an imbalance exists between the level of conservation treatment and the level of inherent vulnerability.* Acres with characteristics such as steeper slopes and soil types that promote surface water runoff are more vulnerable than other acres to sediment and nutrient losses beyond the edge of the field. In addition, acres that are flat with porous soil types are more prone to nutrient losses through subsurface flow pathways.

Conservation treatment needs for the Chesapeake Bay Region:

- Nineteen percent of cropped acres (0.8 million acres) have a **high** level of need for additional conservation treatment; acres with a “high” level of need consist of the most vulnerable of the under-treated acres with the least conservation treatment and the highest losses of sediment and/or nutrients.
- Sixty-one percent of cropped acres (2.6 million acres) have a **moderate** level of need for additional conservation treatment; acres with a “moderate” level of need consist of under-treated acres that generally have lower levels of inherent vulnerability or have more existing conservation practice use than do acres with a high level of need.
- Twenty percent of cropped acres (0.9 million acres) have no or a **low** level of need for additional treatment and are considered to be adequately treated.

The greatest conservation need in the region is complete and consistent use of nutrient management—appropriate rate, form, timing, *and* method of application. In some cases, minor adjustments to an existing nutrient management plan are required to bring it up to current standards (590 practice code for Nutrient Management), whereas other acres require more extensive adjustments that could also include edge-of-field filters or buffers. While most cropped acres have some nutrient management practices in use (see table 9, chapter 3), the study found that 18 percent have a high need for additional treatment to better control nitrogen or phosphorus loss from fields, based on practices in use during 2003–06. About 62 percent of cropped acres have a high or moderate treatment need to address excessive levels of nitrogen loss in subsurface flow pathways, most of which returns to surface water through drainage ditches, tile drains, natural seeps, and groundwater return flow.

Additional soil erosion control is also needed in the region, though the need is less than for nutrient management. Based on practice use during 2003–06, 5 percent of cropped acres have a high need for additional soil erosion control and 20 percent have a moderate need.

Simulation of the effects additional conservation treatment. Model simulations demonstrated that a suite of practices that includes both soil erosion control and comprehensive nutrient management is required to simultaneously address soil erosion *and* nutrient loss through all loss pathways. In practice, a *comprehensive planning process* is used to identify the appropriate combination of practices needed to address multiple resource concerns by taking into account the specific inherent vulnerabilities associated with each field.

Model simulation demonstrated that treatment of the 810,000 acres with a high need for additional treatment would achieve the following gains *for the region as a whole compared to the 2003–2006 baseline*:

- Sediment loss from fields would be reduced by 37 percent.
- Nitrogen lost from fields with surface runoff would be reduced by 27 percent.
- Nitrogen loss from fields in subsurface flows would be reduced by 20 percent.
- Total phosphorus loss from fields would be reduced by 25 percent.

Treatment of all 3.4 million under-treated acres (acres with either a high or moderate need for treatment) would achieve the following gains *for the region as a whole compared to the 2003–2006 baseline*:

- Sediment loss from fields would be reduced by 87 percent.
- Nitrogen lost from the field with surface runoff would be reduced by 66 percent.
- Nitrogen loss from the field in subsurface flows would be reduced by 53 percent.
- Total phosphorus loss would be reduced by 57 percent.

The nutrient management used in these scenarios to simulate additional conservation treatment represents feasible and proven conservation practices that can be successfully applied using today's technology. There are, however, emerging conservation technologies that have the potential to further reduce nutrient loss from farm fields and provide even greater conservation benefits once the technologies become more widespread. These include—

- variable rate technology for precise nutrient application rates and placement methods;
- nitrogen use efficiency enhancers (time release and ammonia loss inhibitors);
- drainage water management which reduces late fall and early spring flushes of nitrate-laden drainage water; and
- constructed wetlands that receive surface water runoff from fields prior to discharge to streams and rivers.

Targeting. Not all acres provide the same benefit from conservation treatment. The more vulnerable acres, such as highly erodible land and soils prone to leaching, inherently lose more sediment or nutrients, therefore greater benefit can be attained with additional conservation treatment. The gains in efficiency by first treating acres with a high level of treatment need are demonstrated in the table below using results from the treatment simulations. For example, treatment of acres with a high level of treatment need would result in an average reduction in sediment loss of 2.3 tons per acre per year for those 810,000 acres. Treatment of acres with a moderate level of treatment need would result in an average reduction in sediment loss of only 1.0 ton per acre per year. Treatment of acres with a low level of need for additional treatment would result in an average reduction in sediment loss of only 0.3 ton per acre per year.

Average annual per-acre reductions in losses from treatment of designated acres with additional erosion control and nutrient management

Resource concern	810,000 acres with a high level of treatment need	2.6 million acres with a moderate level of treatment need	Remaining 872,000 acres with a low level of treatment need
Sediment loss at edge of field due to water erosion (tons/acre)	2.3	1.0	0.3
Total nitrogen loss for all pathways (pounds/acre)	53	26	2
Loss of nitrogen with surface runoff, including waterborne sediment (pounds/acre)	13	6	2
Loss of nitrogen in subsurface flows (pounds/acre)	35	17	<1
Total phosphorus loss for all pathways (pounds/acre)	4.9	2.0	0.3

Effects of Conservation Treatment on Water Quality in the Chesapeake Bay

Reductions in field-level losses due to conservation practices, including land in long-term conserving cover, translate into improvements in water quality in streams and rivers in the region. Transport of sediment, nutrients, and pesticides from farm fields to streams and rivers involves a variety of processes and time-lags, and not all of the potential pollutants leaving fields contribute to instream loads.

What agriculture accomplished through 2006. When considered along with loads from all other sources, conservation practices in use on cultivated cropland in 2003–06, including land in long-term conserving cover, are responsible for reducing total loads delivered to the Bay (all sources) by—

- 10 percent for sediment,
- 14 percent for phosphorus, and
- 14 percent for nitrogen.

Opportunities for additional reductions in sediment and nutrient losses. If all the under-treated acres (3.4 million acres with either a high or moderate need for treatment) were fully treated with the appropriate soil erosion control or nutrient management practices, total loads delivered to the Bay (all sources) would be reduced from *baseline levels* by—

- 6 percent for sediment (bringing loads from cultivated cropland down very close to “background levels”),
- 12 percent for phosphorus, and
- 15 percent for nitrogen.

Background levels represent loads that would be expected if no acres in the watershed were cultivated and were derived by running an additional model scenario that simulated a grass and tree mix cover without any tillage or addition of nutrients or pesticides for all cultivated cropland acres in the watershed. Background loads include loads from all other land uses—hayland, pastureland, forestland, and urban land—as well as point sources.

Chapter 1
Land Use and Agriculture in the Chesapeake Bay Region

Land Use

The Chesapeake Bay region covers about 68,500 square miles and includes parts of New York, Pennsylvania, Maryland, Delaware, Virginia, and West Virginia. The majority of the land cover in the Chesapeake Bay region is forest land, which covers about 59 percent of the region (table 1 and fig. 1). The forests consist primarily of deciduous trees with conifers and mixed stands in some areas. Pastureland and hay land make up about 18 percent of the land cover in the region. About 10 percent of the area is used for crop production. About 6 percent of the area is in water and wetlands.

Urban areas make up about 8 percent of the area. The major metropolitan areas are Washington, DC; Baltimore, MD; Richmond, VA; Norfolk VA; and Harrisburg, PA.
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Table 1. Distribution of land cover in the Chesapeake Bay region

Land use	Acres*	Percent
Cultivated cropland and land enrolled in the CRP General Signup	4,588,332	10
Forest deciduous	19,106,747	44
Hay/Pasture not in rotation with crops	7,738,805	18
Urban	3,651,000	8
Water	1,152,262	3
Wetland forested	793,516	2
Range grasses	142,690	<1
Wetland non-forested	517,632	1
Forest evergreen	2,999,538	7
Forest mixed	2,421,677	6
Range brush	266,807	1
Horticulture and barren	473,994	1
Total	43,853,000	100

Source: 2001 National Land Cover Database for the Conterminous United States (Homer et al., 2007).
*Acreage estimates for cultivated cropland differ slightly from those provided elsewhere in this report because of differences in sources and methods.

Agriculture

The 2007 Census of Agriculture reported 83,775 farms in the Chesapeake Bay region, about 4 percent of the total number of farms in the United States (table 2). Farms in the Chesapeake Bay region make up about 1 percent of all farmland in the nation. According to the 2007 Census of Agriculture, the value of Chesapeake Bay region agricultural sales in 2007 was about $9.5 billion—24 percent from crops and 76 percent from livestock.

About 51 percent of Chesapeake Bay region farms primarily raise crops, about 42 percent are primarily livestock operations, and the remaining 7 percent produce a mix of livestock and crops (table 3).

Most of the farms (74 percent) in 2007 were small operations with less than $50,000 in total farm sales. About 7 percent of the farms had total farm sales greater than $500,000 (table 3). Forty-three percent of the farms in the Chesapeake Bay region are smaller than 50 acres, and 51 percent are between 50 and 500 acres. Only 6 percent of the farms have more than 500 acres (table 3).

Crop production

The Chesapeake Bay region accounts for about 2 percent of all U.S. crop sales (table 2). Corn, soybeans, and hay are the principal crops grown. Wheat is an important secondary crop in terms of acres harvested.

Farmers in the region produced 2 percent of the corn harvested for grain in the United States in 2007—163 million bushels—on about 1.5 million acres. Hay, grass silage, haylage, and greenchop were harvested on 2.2 million acres. Farms in the region also produced 2 percent of the national soybean crop (31.9 million bushels) on 1.1 million acres.

Commercial fertilizers and pesticides are widely used on cultivated cropland throughout the region (table 2). In 2007, 4.1 million acres of cropland were fertilized, 3.3 million acres of cropland and pasture were treated with chemicals for weed control, and 1.7 million acres of cropland were treated for insect control. About 1.7 million acres had manure applied in 2007.

Irrigation is used on some acres to supplement rainfall during dry periods. According to the Census of Agriculture, about 4 percent of the harvested acres were irrigated in 2007.

Livestock operations

Livestock production in the region is dominated by poultry production, followed by dairy. Livestock operations in the region produced 10 percent of all poultry and egg sales in the United States in 2007, exceeding $3.7 billion in value (table 2). Sales of dairy products ranked second in the region at $2.2 billion, representing 7 percent of the U.S. total. Populations of pastured cattle, horses, and ponies are also significant, representing about one-third of the total livestock population in the region in 2007 (table 2).

Although 66 percent of the farms in the Chesapeake Bay region (55,600 farms) reported livestock sales in 2007, the majority are small operations. About 29,000 of these farms had fewer than 30 animal units on the farm; a small number of these had specialty livestock such as rabbits, bison, mink, or deer (table 3). (An animal unit is 1,000 pounds of live animal weight.) Pastured livestock (cattle, horses, sheep, or goats) predominate on about 14,000 farms; 81 percent of these farms raised fewer than 100 animal units in 2007. About 13,700 farms could be defined as animal feeding operations (AFOs). AFOs are typically livestock operations with confined livestock, such as poultry, swine, cattle on feed, or dairies. Sixteen percent of the farms in the Chesapeake Bay region are AFOs, although the bulk of these are relatively small operations. Only about 600 of the livestock operations (4 percent of the AFOs) are large, with livestock numbers in 2007 above the threshold for a concentrated animal feeding operation (CAFO).

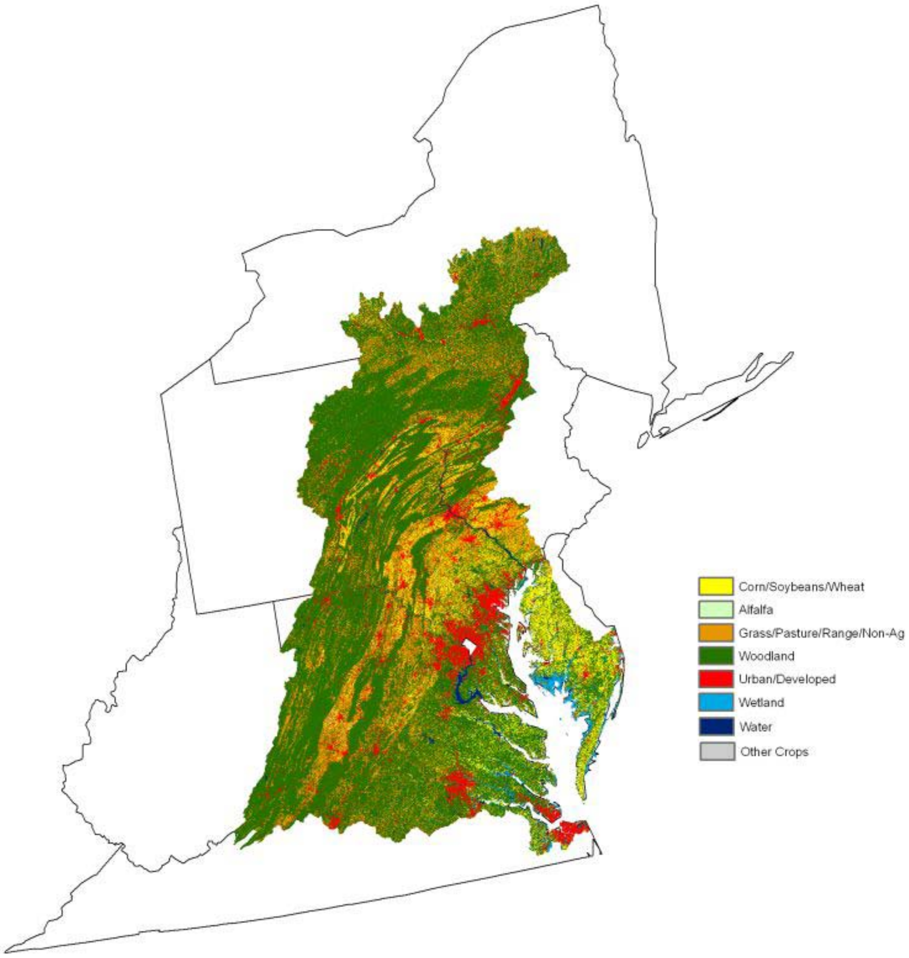
Table 2. Profile of farms in the Chesapeake Bay region, 2007

Characteristic	Value	Percent of national total
Number of farms	83,775	4
Acres on farms	12,826,065	1
Average acres per farm	153	
Cropland harvested, acres	6,027,682	2
Cropland used for pasture, acres	606,584	2
Cropland on which all crops failed, acres	73,359	1
Cropland in summer fallow, acres	39,109	<1
Cropland idle or used for cover crops, acres	447,020	1
Woodland pastured, acres	383,612	1
Woodland not pastured, acres	2,609,960	6
Permanent pasture and rangeland, acres	1,925,684	<1
Other land on farms, acres	713,055	2
Principal crops grown		
Field corn for grain harvested, acres	1,546,362	2
Field corn for silage harvested, acres	551,955	9
Soybeans harvested, acres	1,066,151	2
Wheat harvested, sum acres	455,516	1
Alfalfa hay harvested, acres	436,156	2
Grass silage, haylage, and greenchop harvested, acres	308,028	9
Tame and wild hay harvested, acres	1,506,020	4
Irrigated harvested land, acres	240,438	<1
Irrigated pastureland or rangeland, acres	3,707	<1
Cropland fertilized, acres	4,103,629	2
Pastureland fertilized, acres	410,840	2
Land treated for insects on hay or other crops, acres	1,701,146	2
Land treated for nematodes in crops, acres	111,728	1
Land treated for diseases in crops and orchards, acres	267,317	1
Land treated for weeds in crops and pasture, acres	3,320,537	1
Crops on which chemicals for defoliation applied, acres	77,940	1
Acres on which manure was applied	1,716,448	8
Total grains and oilseeds sales, million dollars	915,631,290	1
Total fruit and berry sales, million dollars	197,357,734	1
Total vegetable, melons sales, million dollars	279,696,733	2
Total nursery, greenhouse, and floriculture sales, million dollars	611,617,415	4
Total hay other crop sales, million dollars	239,943,957	1
Total crop sales, million dollars	2,004,303,172	2
Total dairy sales, million dollars	2,150,033,444	7
Total hog and pigs sales, million dollars	343,587,556	2
Total poultry and eggs sales, million dollars	3,711,452,954	10
Total cattle sales, million dollars	843,470,000	1
Total sheep, goats, and their products sales, million dollars	15,958,047	2
Total horses, ponies, and mules sales, million dollars	107,465,458	5
Total other livestock sales, million dollars	99,358,748	4
Total livestock sales, million dollars	7,271,326,207	5
Animal units on farms		
All livestock types	3,221,469	3
Swine	187,118	2
Dairy cows	853,938	7
Fattened cattle	107,140	1
Other cattle, horses, sheep, goats	1,229,906	2
Chickens, turkeys, and ducks	831,182	10
Other livestock	12,185	3

Source: 2007 Census of Agriculture, National Agricultural Statistics Service, USDA

Note: Information in the Census of Agriculture was used to estimate animal units using methods and assumptions described in USDA-NRCS (2003).

Figure 1. Land cover in the Chesapeake Bay region



Source: National Agricultural Statistics Service (NASS 2007).

Table 3. Characteristics of farms in the Chesapeake Bay region, 2007

	Number of farms	Percent of farms in Chesapeake Bay region
Farming primary occupation	39,584	47
Farm size:		
<50 acres	36,142	43
50–500 acres	42,795	51
500–2,000 acres	4,399	5
>2,000 acres	439	1
Farm sales:		
<$10,000	45,013	54
$10,000–50,000	16,754	20
$50,000–250,000	11,217	13
$250,000–500,000	4,657	6
>$500,000	6,134	7
Farm type:		
Crop sales make up more than 75% of farm sales	42,630	51
Livestock sales make up more than 75% of farm sales	35,334	42
Mixed crop and livestock sales	5,811	7
Farms with no livestock sales	28,187	34
Farms with few livestock or specialty livestock types	27,751	33
Farms with pastured livestock and few other livestock types	14,143	17
Farms with animal feeding operations (AFOs)*	13,694	16

Source: 2007 Census of Agriculture, National Agricultural Statistics Service, USDA

* AFOs, as defined here, typically have a total of more than 12 animal units consisting of fattened cattle, dairy cows, hogs and pigs, chickens, ducks, and turkeys.

Watersheds

A hydrologic accounting system consisting of water resource regions, major subregions, and smaller watersheds has been defined by the U.S. Geological Survey (USGS) (1980). In this study, the Chesapeake Bay region is represented by four subregions within the Mid-Atlantic Water Resource Region. Each water resource region is designated with a 2-digit code, which is further divided into 4-digit subregions and then into 8-digit watersheds, or Hydrologic Unit Codes (HUCs).

The four subasins within the Chesapeake Bay region are shown in figure 2, and agricultural land use within each subregion is summarized in table 4. The highest concentration of cultivated cropland, 24 percent) is in subregion 0206—the Upper Chesapeake Bay subregion. The Susquehanna River subregion has about 11 percent of the land base in cultivated cropland. The remaining two subregions have 5.5 to 6.5 percent of the land base in cultivated cropland. About three-fourths of the cultivated cropland in the region is in the Susquehanna River and Upper Chesapeake Bay subregions.

Estimates presented in this report for field-level effects of conservation practices (chapters 3-5) are for the Chesapeake Bay region, whereas estimates of instream water quality effects (chapter 6) are for the Chesapeake Bay watershed. The Chesapeake Bay watershed *excludes* two 8-digit watersheds in the Upper Chesapeake Bay subregion that drain to the Atlantic Ocean (8-digit HUCs 02060010 and 02080110). The area that *includes* these two watersheds is referred to as the Chesapeake Bay region.

Figure 2. Percent cultivated cropland, including land in long-term conserving cover, for the four subregions in the Chesapeake Bay region

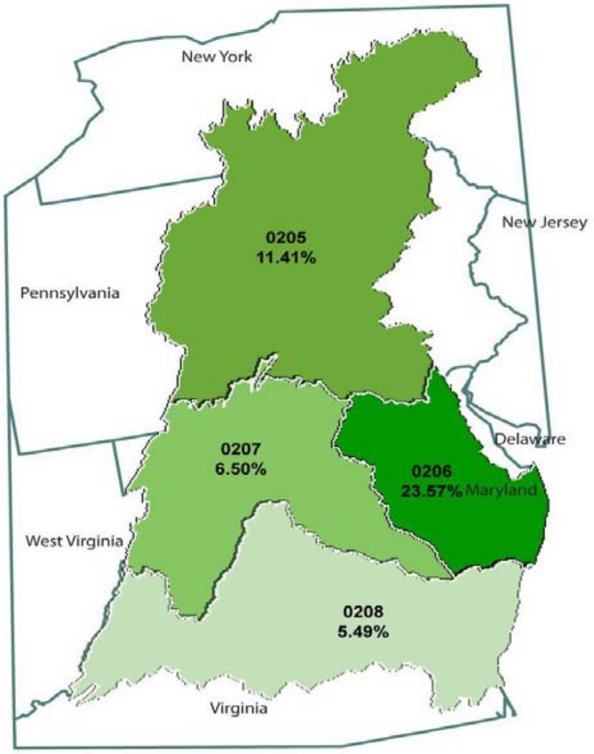


Table 4. Agricultural land use in the four subregions in the Chesapeake Bay region

Sub-region code	Subregion name	Total land (1,000 acres)	Cultivated cropland (1,000 acres)*	Percent cultivated cropland in subregion	Percent of cultivated cropland in Chesapeake Bay region	Percent of cultivated cropland acres in long-term conserving cover	Hayland not in rotation with crops (1,000 acres)	Pastureland not in rotation with crops (1,000 acres)
0205	Susquehanna River	17,596	2,008	11.4	43.8	4.0	1,315	1,438
0206	Upper Chesapeake Bay	5,773	1,361	23.6	29.7	1.1	54	879
0207	Potomac River	9,404	612	6.5	13.3	2.0	670	1,566
0208	Lower Chesapeake Bay	11,080	608	5.5	13.2	4.2	461	1,356
	Total	43,853	4,588	10.5	100.0	2.9	2,500	5,239

Source: 2001 National Land Cover Database for the Conterminous United States (Homer et al. 2007) and the 1997 National Resources Inventory (USDA-NRCS, 2002).
* Acres of cultivated cropland include land in long-term conserving cover. Estimates of cultivated cropland were obtained from HUMUS databases on land use, differing slightly from acreage estimates obtained with the NRI-CEAP sample.

Chapter 2
Overview of Sampling and Modeling Approach

Scope of Study

This study was designed to evaluate the effects of conservation practices at the regional scale to provide a better understanding of how conservation practices are benefiting the environment and to determine what challenges remain. The report does the following.

- Evaluates the extent of conservation practice use in the region;
- Estimates the environmental benefits and effects of Conservation practices in use;
- Estimates conservation treatment needs for the region; and
- Estimates potential gains that could be attained with additional conservation treatment.

The study was designed to quantify the level the effects of commonly used conservation practices on cultivated cropland, regardless of how or why the practices came to be in use. This assessment is not an evaluation of Federal conservation programs, because it is not restricted to only those practices associated with Federal conservation programs.

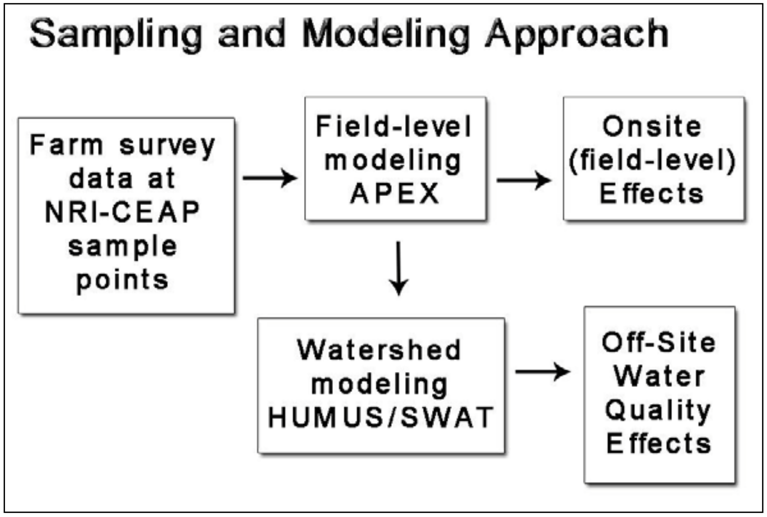
The Chesapeake Bay region has about 4.4 million acres of cultivated cropland—4.3 million cropped acres and about 0.1 million acres in long-term conserving cover. For purposes of this report, cultivated cropland includes land in row crops or close-grown crops, hay and pasture in rotation with row crops and close-grown crops, and land in long-term conserving cover. Cultivated cropland does not include agricultural land that has been in hay, pasture, or horticulture for 4 or more consecutive years. Acres enrolled in the General Signup of the Conservation Reserve Program (CRP) were used to represent cultivated cropland currently in long-term conserving cover.

Sampling and Modeling Approach

The assessment uses a statistical sampling and modeling approach to estimate the environmental effects and benefits of conservation practices (fig. 3).

- A subset of 771 National Resources Inventory (NRI) sample points provides a statistical sample that represents the diversity of soils and other conditions for cropped acres in the Chesapeake Bay region. The sample also includes 61 additional NRI sample points designated as CRP acres to represent land in long-term conserving cover. NRI sample points are linked to NRCS Soil Survey databases and were linked spatially to climate databases for this study.
- A farmer survey—the NRI-CEAP Cropland Survey—was conducted at these sample points during the period 2003–06 to determine what conservation practices were in use and to collect information on farming practices.
- The field-level effects of the conservation practices were assessed using a field-scale physical process model—the Agricultural Policy Environmental Extender (APEX)—which simulates the day-to-day farming activities, wind and water erosion, loss or gain of soil organic carbon, and edge-of-field losses of soil, nutrients, and pesticides.
- A watershed model and system of databases—the Hydrologic Unit Model for the United States (HUMUS)—was used to simulate how reductions of field losses have reduced instream concentrations and loadings of sediment, nutrients, and pesticides within the Chesapeake Bay region. The SWAT model (Soil and Water Assessment Tool) was used to simulate nonpoint source loadings from land uses other than cropland and to route instream loads from one watershed to another.

Figure 3. **S**tatistical sampling and modeling approach used to simulate the effects of conservation practices



The modeling strategy for estimating the effects of conservation practices consists of two model scenarios that are produced for each sample point.

1. A baseline scenario, the "baseline conservation condition" scenario, provides model simulations that account for cropping patterns, farming activities, and conservation practices as reported in the NRI-CEAP Cropland Survey and other sources.
2. An alternative scenario, the "no-practice" scenario, simulates model results as if no conservation practices were in use but holds all other model inputs and parameters the same as in the current conservation condition scenario.

The effects of conservation practices are obtained by taking the difference in model results between the two scenarios (fig. 4).[1] For example, to simulate "no practices" for sample points where some type of residue management is used, model simulations were conducted as if continuous conventional tillage had been used. Similarly, for sample points with structural conservation practices (buffers, terraces, grassed waterways, etc.), the no-practice scenario was simulated as if the practices were not present. The no-practice representation for land in long-term conserving cover was derived from model results for cropped acres as simulated in the no-practice scenario, representing how the land would have been managed had crops been grown without the use of conservation practices.

The approach captures the diversity of land use, soils, climate, and topography from the NRI; accounts for site-specific farming activities; estimates the loss of materials at the field scale where the science is most developed; and provides a statistical basis for aggregating results to the national and regional levels.

The NRI and the CEAP Sample

The approach is an extension of the NRI, a longitudinal, scientifically-based survey designed to gauge natural resource status, conditions, and trends on the Nation's non-Federal land (Goebel 1998; USDA-NRCS 2002). NRCS has previously used the NRI for modeling to address issues related to natural resources and agriculture (Goebel and Kellogg 2002).[2]

Figure 4. Modeling strategy used to assess effects of conservation practices

Modeling Strategy

1. Estimate a CEAP Baseline using farmer survey information at NRI sample points

2. Construct an alternative scenario assuming "no practices"

Difference between these two scenarios represents the benefits of the accumulation of conservation practices currently in place on the landscape.

The NRI sampling design implemented in 1982 provided a stratified, two-stage, unequal probability area sample of the entire country (Goebel and Baker 1987; Nusser and Goebel 1997). Nominally square areas/segments were selected within geographical strata on a county-by-county basis; specific point locations were selected within each selected segment. The segments ranged in size from 40 to 640 acres but were typically half-mile square areas, and most segments contained three sample points. At each sample point, information is collected on nearly 200 attributes; some items are also collected for the entire segment. The sampling rates for the segments were variable, typically from 2 to 6 percent in agricultural strata and much lower in remote nonagricultural areas. The 1997 NRI Foundation Sample contained about 300,000 sample segments and about 800,000 sample points.

NRCS made several significant changes to the NRI program over the past 10 years, including transitioning from a 5-year periodic survey to an annual survey. The NRI's annual design is a *supplemented panel design.* A *core panel* of 41,000 segments is sampled each year, and *rotation (supplemental) panels* of 31,000 segments each vary by inventory year and allow an inventory to focus on an emerging issue. The core panel and the various supplemental panels are unequal probability subsamples from the 1997 NRI Foundation Sample.[3]

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[1] This modeling strategy is similar to how the NRI produces estimates of soil erosion and the intrinsic erosion rate used to identify highly erodible land. The NRI uses the Universal Soil Loss Equation (USLE) to estimate sheet and rill erosion at each sample point on the basis of site-specific factors. Soil loss per unit area is equal to R*K*L*S*C*P. The first four factors—R, K, L, S—represent the conditions of climate, soil, and topography existing at a site. (USDA 1989). The last two factors—C and P—represent the degree to which management influences the erosion rate. The product of the first four factors is sometimes called the intrinsic, or potential, erosion rate. The intrinsic erosion rate divided by T, the soil loss tolerance factor, produces estimates of EI, the erodibility index. The intrinsic erosion rate is thus a "no-practice" representation of sheet and rill erosion, since C=1 represents smooth-tilled continuous fallow and P=1 represents no supporting practices.

[2] Previous studies have used this NRI micro-simulation modeling approach to estimate soil loss, nutrient loss, and change in soil organic carbon (Potter et al. 2006), to estimate pesticide loss from cropland (Kellogg et al. 1992, 1994, 2002; Goss et al. 1998), and to identify priority watersheds for water quality protection from nonpoint sources related to agriculture (Kellogg 2000, Kellogg et al. 1997).

[3] For more information on the NRI sample design, see www.nrcs.usda.gov/technical/NRI/.

The CEAP cultivated cropland sample is a subset of NRI sample points from the 2003 NRI (USDA/NRCS 2007). The 2001, 2002, and 2003 Annual NRI surveys were used to draw the sample.[4] The sample is statistically representative of cultivated cropland and formerly cultivated land currently in long-term conserving cover. Nationally, the NRI-CEAP sample consists of about 18,700 NRI points representing cropped acres, and about 13,000 NRI points representing land enrolled in the General Signup of the CRP.

The Chesapeake Bay region portion of the NRI-CEAP sample consists of 771 sample points representing 4.3 million cropped acres and 61 sample points representing 0.1 million acres of agricultural land in long-term conserving cover. Table 5 provides a breakdown of sample sizes for the dominant cropping systems that occur in the Chesapeake Bay region. About 89 percent of the cultivated cropland acres include corn or soybean or both in the crop rotation.

Nationally, there were over 30,000 samples in the original sample draw. A completed farmer survey was required to include the sample point in the CEAP sample. Some farmers declined to participate in the survey, others could not be located during the time period scheduled for implementing the survey, and other sample points were excluded for administrative reasons such as overlap with other USDA surveys. Some sample points were excluded because the surveys were incomplete or contained inconsistent information, land use found at the sample point had recently changed and was no longer cultivated cropland, or because the crops grown were uncommon and model parameters for crop growth were not available.

The CEAP sample was designed to allow reporting of results for the four subregions (4-digit HUCs) within the region. The acreage weights were derived so as to approximate total cropped acres by 4-digit HUC as estimated by the full 2003 NRI. The sample size is too small, in most cases, for reliable and defensible reporting of results for areas below the subregion level. Acres reported using the CEAP sample are “estimated” acres because of the uncertainty associated with the statistical sample. Margins of error for estimated acres used in this report are provided in appendix A.

The NRI-CEAP Cropland Survey

A farmer survey—the NRI-CEAP Cropland Survey—was conducted to obtain the additional information needed for modeling the 771 sample points with crops.[5] The USDA National Agricultural Statistics Service (NASS) administered the survey. Farmer participation was voluntary, and the information gathered is confidential. The survey content was specifically designed to provide information on farming activities for use with a physical process model to estimate field-level effects of conservation practices.

The survey obtained information on—

- crops grown for the previous 3 years, including double crops and cover crops;
- field characteristics, such as proximity to a water body or wetland and presence of tile or surface drainage systems;
- conservation practices associated with the field;
- crop rotation plan;
- application of commercial fertilizers (rate, timing, method, and form) for crops grown the previous 3 years;
- application of manure (source and type, consistency, application rate, method, and timing) on the field over the previous 3 years;
- application of pesticides (chemical, rate, timing, and method) for the previous 3 years;
- pest management practices;
- irrigation practices (system type, amount, and frequency);
- timing and equipment used for all field operations (tillage, planting, cultivation, harvesting) over the previous 3 years, and;
- general characteristics of the operator and the operation.

In a separate survey, NRCS field offices provided information on the practices specified in conservation plans.

Because of the large size of the sample, it was necessary to spread the data collection process over a 4-year period, from 2003 through 2006. In each year, surveys were obtained for a separate set of sample points. The final CEAP sample was constructed by pooling the set of usable, completed surveys from all four years.

Simulating the Effects of Weather

Weather is the predominant factor determining the loss of soil, nitrogen, phosphorus, and pesticides from farm fields, as well as the effects of conservation practices. To capture the effects of weather, each scenario was simulated using 47 years of actual daily weather data for the time period 1960 through 2006. The 47-year record is the extent of a serially complete daily data set of weather station data from weather station records available from the NCDC (National Climatic Data Center), for the period 1960 to 2006, including precipitation, temperature maximum, and temperature minimum (Eischeid et al. 2000). These data were combined with the respective PRISM (Parameter–Elevation Regressions on Independent Slopes Model; Daly et al. 1994) monthly map estimates to construct daily estimates of precipitation and temperature (Di Luzio et al. 2008). The same 47-year weather data were used in the HUMUS/SWAT simulations and in the APEX model simulations.

Annual precipitation over the 47-year simulation averaged about 42 inches for cropped acres in this region. Annual precipitation varied substantially in the model simulations, both within the region and from year to year, as shown in figures 5 and 6.

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[4] Information about the CEAP sample design is in “NRI-CEAP Cropland Survey Design and Statistical Documentation,” available at http://www.nrcs.usda.gov/technical/nri/ceap/Cropland.html.

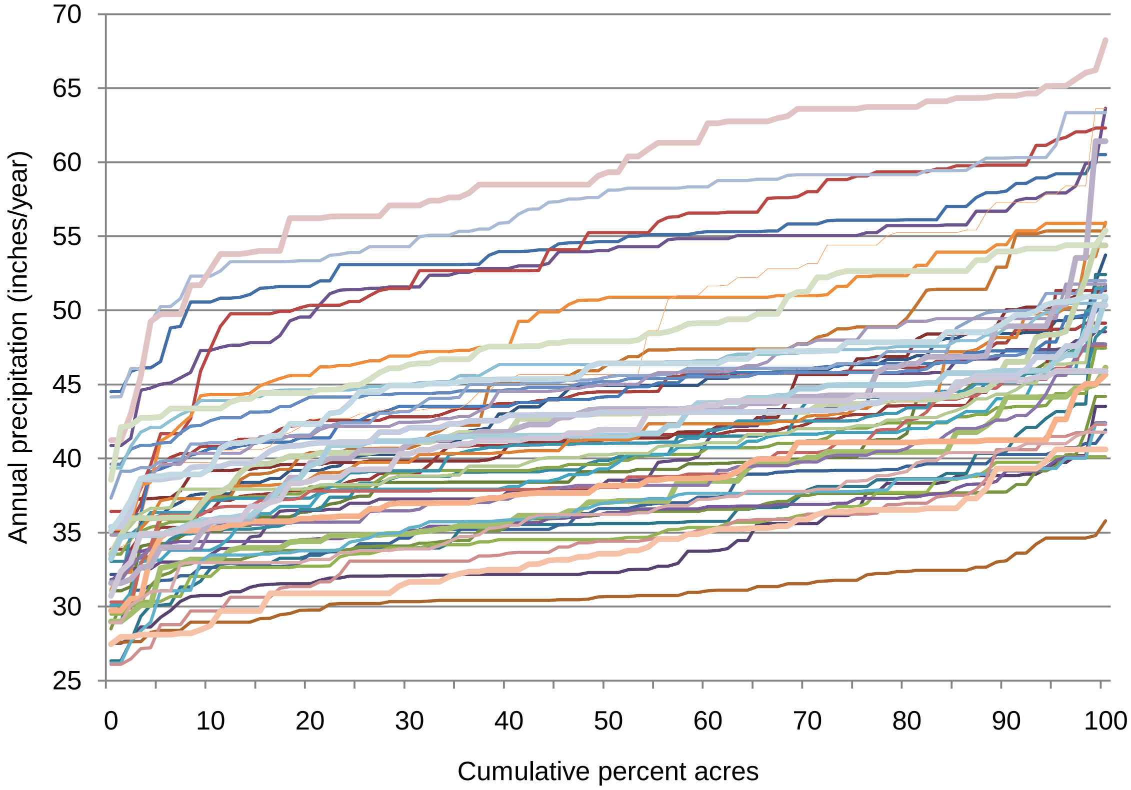
[5] The surveys, the enumerator instructions, and other documentation can be found at www.nrcs.usda.gov/technical/nri/ceap/surveys.html.

Table 5. Cultivated cropland in the Chesapeake Bay region

Cropping System	Number of CEAP samples	Estimated acres	Percent of acres
Corn-soybean only	246	1,174,736	27
Corn-soybean with close grown crops	180	830,308	19
Corn only	103	690,403	16
Soybean only	40	161,087	4
Soybean-wheat only	22	124,649	3
Corn and close grown crops	46	295,685	7
Vegetable or tobacco with or without other crops	24	139,064	3
Hay-crop mix (rotations include corn or soybean)	85	688,255	16
Remaining mix of crops	25	175,713	4
Sub-total for cropped acres	771	4,279,900	98
CRP General Signup, representing cultivated cropland in long-term conserving cover	61	100,300	2
Total	832	4,380,200	100

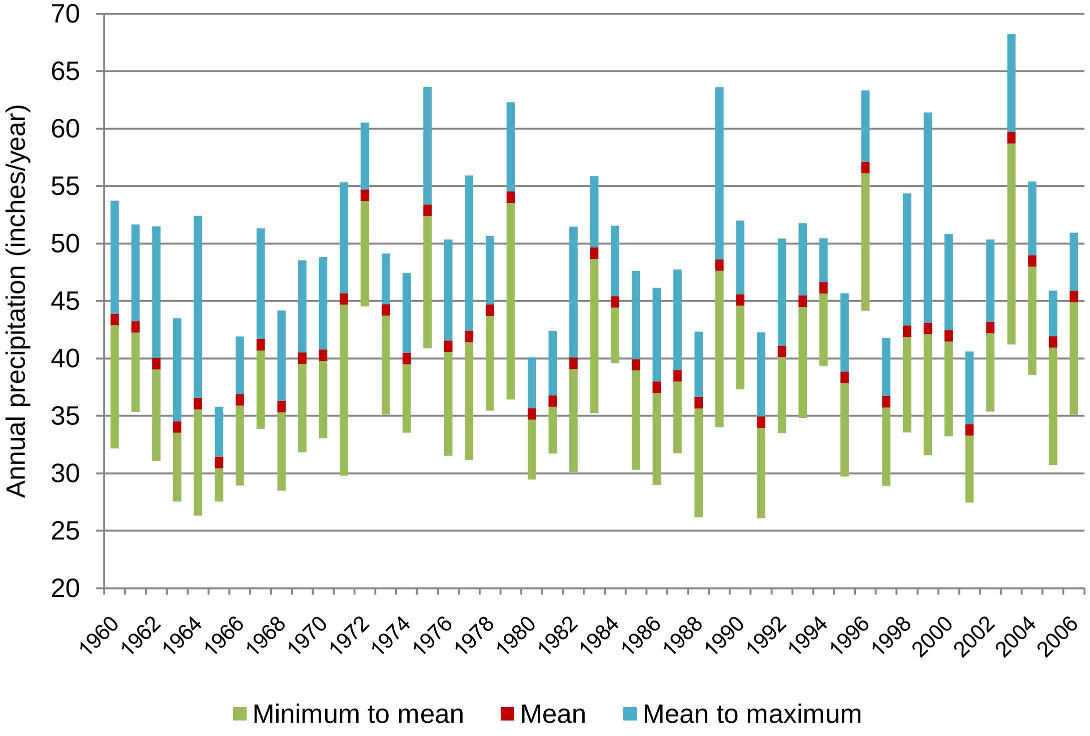
Note: Estimates are from the 2003 NRI and the NRI-CEAP Cropland Survey. Cultivated cropland acres in this table differ slightly from estimates presented in table 1 because of differences in sources and methods.

Figure 5. Cumulative distributions of annual precipitation used in the model simulations for cropped acres in the Chesapeake Bay region



Note:. Each of the 47 curves shown above represents a single year of data and shows how annual precipitation varies over the region in that year, starting with the driest acres within the region and increasing to the wettest acres for each year. The family of curves shows how annual precipitation varies from year to year. Annual precipitation over the 47-year simulation averaged about 42 inches for cropped acres.

Figure 6. Mean, minimum, and maximum levels of annual precipitation used in the model simulations for cropped acres in the Chesapeake Bay region



Each curve in figure 5 shows how annual precipitation varied over the region in one of the 47 years. The family of curves shows the variability from year to year. The top curve shown is for the year 2003, the wettest year in this region during the 47 years. The curve for 2003 shows that precipitation exceeded 56 inches for about 82 percent of cropped acres in the Chesapeake Bay region.

The drier parts of the region received about 33 inches of precipitation per year, on average, and the wettest parts of the region received about 51 inches per year, on average. Year-to-year variability is especially pronounced—the annual average precipitation amount (representing all cropped acres) ranged from 31 inches in 1965 to 59 inches in 2003 over the 47-years (fig. 6).

Throughout most of this report model results are presented in terms of the 47-year averages where weather is the only input variable that changes year to year. Since we used the cropping patterns and practices for the 2003–06 period, we did not simulate *actual* loses for each of these years. Rather, we provide estimates of what model outputs would *average* over the long term if weather varied as it has over the past 47 years. Similarly, estimates of the average effects of conservation practices include effectiveness in extreme weather years, such as floods and prolonged droughts, as represented in the 47-year weather record.

Chapter 3
Evaluation of Conservation Practice Use—the Baseline Conservation Condition

This study assesses the use and effectiveness of conservation practices in the Chesapeake Bay region for the period 2003 to 2006 to determine the baseline conservation condition for the region. The baseline conservation condition provides a benchmark for estimating the effects of existing conservation practices as well as projecting the likely effects of alternative conservation treatment. Conservation practices that were evaluated include structural practices, annual practices, and long-term conserving cover.

Structural conservation practices, once implemented, are usually kept in place for several years. Designed primarily for erosion control, they also mitigate edge-of-field nutrient and pesticide loss. Structural practices evaluated include—

- in-field practices for water erosion control, divided into two groups:
  - practices that control overland flow (terraces, contour buffer strips, contour farming, stripcropping, contour stripcropping), and
  - practices that control concentrated flow (grassed waterways, grade stabilization structures, diversions, and other structures for water control);
- edge-of-field practices for buffering and filtering surface runoff before it leaves the field (riparian forest buffers, riparian herbaceous cover, filter strips, field borders); and
- wind erosion control practices (windbreaks/shelterbelts, cross wind trap strips, herbaceous wind barriers, hedgerow planting).

*Annual conservation practic*es are management practices that are conducted as part of the crop production system each year. These practices are designed primarily to promote soil quality, reduce in-field erosion, and reduce the availability of sediment, nutrients, and pesticides for transport by wind or water. They include—

- residue and tillage management;
- nutrient management practices;
- pesticide management practices; and
- cover crops.

Long-term conservation cover establishment consists of planting suitable native or domestic grasses, forbs, or trees on environmentally sensitive cultivated cropland.

Historical Context for Conservation Practice Use

The use of conservation practices in the Chesapeake Bay region closely reflects the history of Federal conservation programs and technical assistance. In the beginning the focus was almost entirely on reducing soil erosion and preserving the soil's productive capacity. In the 1930s and 1940s, Hugh Hammond Bennett, the founder and first chief of the Soil Conservation Service (now Natural Resources Conservation Service) instilled in the national ethic the need to treat every acre to its potential by controlling soil erosion and water runoff. Land shaping structural practices (such as terraces, contour farming, and strip cropping) and sediment control structures were widely adopted. Conservation tillage emerged in the 1960s and 1970s as a key management practice for enhancing soil quality and further reducing soil erosion. Conservation tillage, along with use of crop rotations and cover crops, was used either alone or in combination with structural practices. The conservation compliance provisions in the 1985 Farm Bill sharpened the focus to treatment of the most erodible acres, tying farm commodity payments to conservation treatment of highly erodible land. The Conservation Reserve Program was established to enroll the most erodible cropland acres in multi-year contracts to plant acres in long-term conserving cover.

During the 1990s, the focus of conservation efforts began to shift from soil conservation and sustainability to reducing pollution impacts associated with agricultural production. Prominent among new concerns were the environmental effects of nutrient export from farm fields. Traditional conservation practices used to control surface water runoff and erosion control were mitigating a significant portion of these nutrient losses. Additional gains were being achieved using nutrient management practices—application of nutrients (appropriate timing, rate, method, and form) to minimize losses to the environment and maximize the availability of nutrients for crop growth.

Summary of Practice Use

Given the long history of conservation in the Chesapeake Bay region, it is not surprising to find that nearly all cropped acres in the region have evidence of some kind of conservation practice, especially erosion control practices. The conservation practice information collected during the study was used to assess the extent of conservation practice use. Key findings are the following.

- Structural practices for controlling water erosion are in use on 46 percent of cropped acres. On the 44 percent of the acres designated as highly erodible land, structural practices designed to control water erosion are in use on 63 percent of those acres.
- Reduced tillage is common in the region; 88 percent of the cropped acres meet criteria for either no-till (48 percent) or mulch till (40 percent). All but 7 percent of the acres had evidence of some kind of reduced tillage on at least one crop.
- About 43 percent of cropped acres are gaining soil organic carbon. An additional 33 percent of cropped acres are considered to be "maintaining" soil organic carbon (average annual loss less than 100 pounds per acre). Overall, 76 percent of cropped acres are maintaining or enhancing soil organic carbon.
- Producers use either residue and tillage management practices or structural practices, or both, on 96 percent of the acres.
- While most acres have evidence of some nitrogen or phosphorus management, the majority of the acres in the region lack consistent use of appropriate rates, timing,

and method of application on each crop in every year of production, including nearly all of the acres receiving manure.
  - Appropriate timing of nitrogen applications is in use on about 54 percent of the acres for all crops in the rotation.
  - About 35 percent of cropped acres meet criteria for appropriate nitrogen application rates for all crops in the rotation.
  - Appropriate nitrogen application rates, timing of application, and application method for all crops during every year of production, however, are in use on only about 13 percent of cropped acres.
  - Good phosphorus management practices (appropriate rate, timing, and method) are in use on 17 percent of the acres on all crops during every year of production.
  - Only about 9 percent of cropped acres meet full nutrient management criteria for *both* phosphorus and nitrogen management, including acres not receiving nutrient applications.
- Cover crop use during the 2003–06 period of data collection was restricted to only about 4 percent of the acres in the region.
- An Integrated Pest Management (IPM) indicator showed that only about 8 percent of the acres were being managed at a relatively high level of IPM.
- Land in long-term conserving cover, as represented by enrollment in the CRP General Signup, consists of about 100,000 acres in the region (2 percent of cultivated cropland), of which 67 percent is highly erodible land.

Structural Conservation Practices

Data on structural practices for the farm field associated with each sample point were obtained from four sources:

1. **The NRI-CEAP Cropland Survey** included questions about the presence of 12 structural practices: terraces, grassed waterways, vegetative buffers (in-field), hedgerow plantings, riparian forest buffers, riparian herbaceous buffers, windbreaks or herbaceous wind barriers, contour buffers (in-field), field borders, filter strips, critical area planting, and grade stabilization structures.
2. For fields with conservation plans, **NRCS field offices** provided data on all structural practices included in the plans.
3. **The USDA-Farm Service Agency** (FSA) provided practice information for fields that were enrolled in the Continuous CRP for these structural practices: contour grass strips, filter strips, grassed waterways, riparian buffers (trees), and field windbreaks (Alex Barbarika, USDA/FSA, personal communication).
4. **The 2003 NRI** provided additional information for practices that could be reliably identified from overhead photography as part of the NRI data collection process. These practices include contour buffer strips, contour farming, contour stripcropping, field stripcropping, terraces, cross wind stripcropping, cross wind trap strips, diversions, field borders, filter strips, grassed waterways or outlets, hedgerow planting, herbaceous wind barriers, riparian forest buffers, and windbreak or shelterbelt establishment.

Overland flow control practices are designed to slow the movement of water across the soil surface to reduce surface water runoff and sheet and rill erosion. NRCS practice standards for overland flow control include terraces, contour farming, stripcropping, in-field vegetative barriers, and field borders. This is the most prevalent group of structural practices in the Chesapeake Bay region; these practices are found on about 34 percent of the cropped acres in the region; including 51 percent of the highly erodible land (table 6).

Concentrated flow control practices are designed to prevent the development of gullies along flow paths within the field. NRCS practice standards for concentrated flow control practices include grassed waterways, grade stabilization structures, diversions, and water and sediment control basins. About 17 percent of the cropped acres have one or more of these practices, including 29 percent of the highly erodible land (table 6).

Edge-of-field buffering and filtering practices, consisting of grasses, shrubs, and/or trees, are designed to capture the surface runoff losses that were not avoided or mitigated by the in-field practices. NRCS practice standards for edge-of-field mitigation practices include edge-of-field filter strips, riparian herbaceous buffers, and riparian forest buffers. CRP’s buffer practices are included in this category. Edge-of-field buffering and filtering practices are in use on about 10 percent of all cropped acres in the region (table 6).

Overall, about 46 percent of the cropped acres in the Chesapeake Bay region are treated with one or more water erosion control structural practices (table 6). The treated percentage for highly erodible land acres is higher—63 percent.

At each sample point, structural conservation practices for water erosion control were classified as either a high, moderately high, moderate, or low level of treatment according to criteria presented in figure 7. About 5 percent of cropped acres in the region have a high level of treatment (combination of edge-of-field buffering or filtering and at least one in-field structural practice). About 54 percent of the acres do not have structural practices for water erosion control; however, about 40 percent of these acres have slopes less than 2 percent, some of which may not need to be treated with structural practices. These treatment levels are combined with soil risk classes to estimate acres that appear to be under-treated for water erosion control in chapter 5

Wind erosion control practices are designed to reduce the force of the wind on the field. NRCS practice standards for wind erosion control practices include cross wind ridges, cross wind trap strips, herbaceous wind barriers, and windbreak/shelterbelt establishment. Wind erosion is not a resource concern for most acres in this region. Only about 7 percent of the cropped acres in the region are treated for wind erosion using structural practices (table 6).
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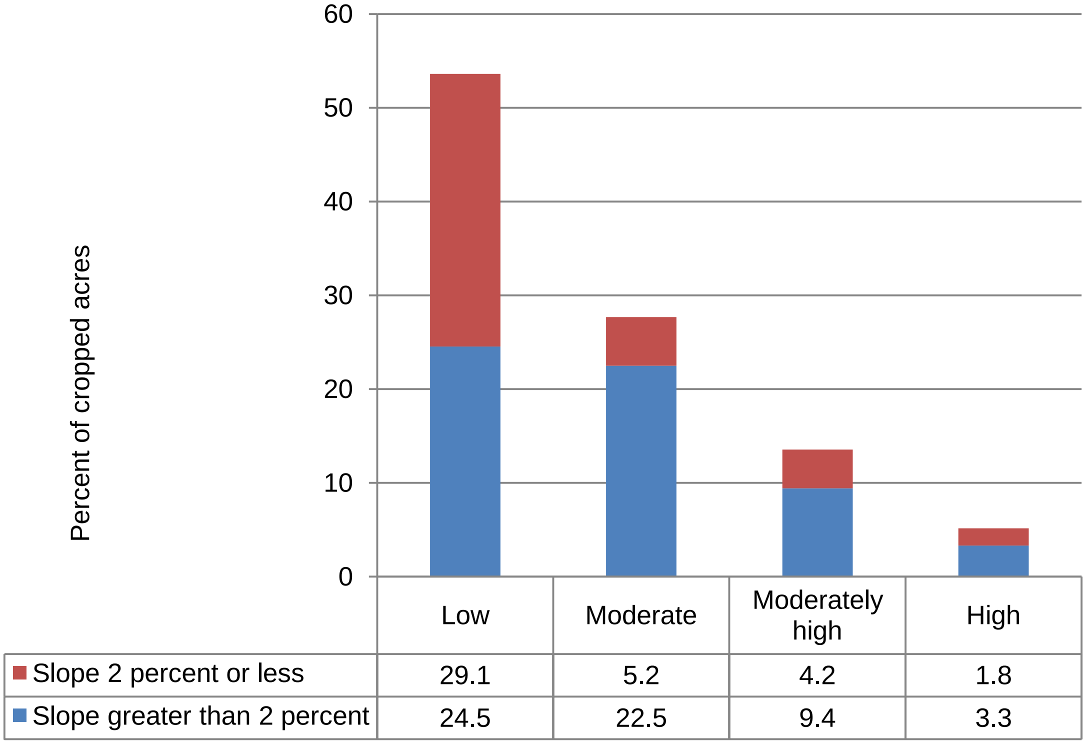
Table 6. Structural conservation practices in use for the baseline conservation condition, Chesapeake Bay region

Structural practice category	Conservation practice in use	Percent of non-HEL	Percent of HEL	Percent of cropped acres
Overland flow control practices	Terraces, contour buffer strips, contour farming, stripcropping, contour stripcropping, field border, in-field vegetative barriers	20	51	34
Concentrated flow control practices	Grassed waterways, grade stabilization structures, diversions, other structures for water control	8	29	17
Edge-of-field buffering and filtering practices	Riparian forest buffers, riparian herbaceous buffers, filter strips	12	8	10
One or more water erosion control practice	Overland flow, concentrated flow, or edge-of-field practice	33	63	46
Wind erosion control practices	Windbreaks/shelterbelts, crosswind trap strips, herbaceous windbreak, hedgerow planting	5	9	7

Note: About 44 percent of cropped acres in the Chesapeake Bay region are highly erodible land (HEL). Soils are classified as HEL if they have an erodibility index (EI) score of 8 or higher. A numerical expression of the potential of a soil to erode, EI considers the physical and chemical properties of the soil and climatic conditions where it is located. The higher the index, the greater the investment needed to maintain the sustainability of the soil resource base if intensively cropped.

Figure 7. Conservation treatment levels for structural practices, baseline conservation condition, Chesapeake Bay region



	Low	Moderate	Moderately high	High
🟥 Slope 2 percent or less	29.1	5.2	4.2	1.8
🟦 Slope greater than 2 percent	24.5	22.5	9.4	3.3

Criteria for four levels of treatment with structural conservation practices are:

- **High treatment**: Edge-of-field mitigation *and* at least one in-field structural practice (concentrated flow or overland flow practice) required.
- **Moderately high treatment**: Either edge-of-field mitigation required or both concentrated flow and overland flow practices required.
- **Moderate treatment**: No edge-of-field mitigation, either concentrated flow or overland flow practices required.
- **Low treatment**: No edge-of-field or in-field structural practices.

Residue and Tillage Management Practices

Simulations of the use of residue and tillage management practices were based on the field operations and machinery types reported in the NRI-CEAP Cropland Survey for each sample point. The survey obtained information on the timing, type, and frequency of each tillage implement used during the previous 3 years, including the crop to which the tillage operation applied.

The Soil Tillage Intensity Rating (STIR) (USDA-NRCS 2007) was used to determine the soil disturbance intensity for each crop at each sample point. The soil disturbance intensity is a function of the kinds of tillage, the frequency of tillage, and the depth of tillage. STIR values were calculated for each crop and for each of the 3 years covered by the NRI-CEAP Cropland Survey (accounting for multiple crops or cover crops). By combining the STIR values for each crop year with model output on the long-term trend in soil organic carbon gain or loss, eight categories of residue and tillage management were identified, as defined in table 7.

Overall, 88 percent of cropped acres in the Chesapeake Bay region meet the tillage intensity rating for no-till or mulch till (table 7). About 48 percent meet the criteria for no-till—27 percent with gains in soil organic carbon and 21 percent with soil organic carbon loss. About 40 percent meet the tillage intensity criteria for mulch till—13 percent with gains in soil organic carbon and 26 percent with soil organic carbon loss. No-till is used on a slightly higher percentage of highly erodible land than of non-highly erodible land. Only 7 percent of the acres are conventionally tilled for all crops in the rotation.

Most of the cropped acres (96 percent) in the Chesapeake Bay region have some kind of water erosion control practice—either reduced tillage or structural practices or both (table 8). About 40 percent meet tillage intensity for no-till or mulch till and have structural practices, including 57 percent of highly erodible land. Only 4 percent have no water erosion control practices.

Four levels of treatment for residue and tillage management practices were derived according to criteria presented in figure 8. These treatment levels are combined with soil risk classes to estimate acres that appear to be under-treated for water erosion control in chapter 5. The high and moderately high treatment levels represent the 40 percent of cropped acres that meet tillage intensity criteria for either no-till or mulch till with gains in soil organic carbon. The high treatment level (35 percent of the acres) includes only those acres where the tillage intensity criteria are met for *each* crop in the rotation. The majority of the acres have a moderate level of treatment because soil organic carbon is not being enhanced. Only 5 percent of the acres have a low treatment level, consisting of continuous conventional tillage for all crops in the rotation and loss of soil organic carbon.

The evaluation of conservation practices and associated estimates of conservation treatment needs are based on practice use derived from a farmer survey conducted during the years 2003–06. Since that time, however, the six States in the Chesapeake Bay watershed have continued to work with farmers to enhance conservation practice adoption in a joint effort to reduce nonpoint source pollution contributing to water quality issues in the Bay. In Maryland, for example, the state offered expanded incentive payments for the planting of cover crops starting in the 2008–09 growing season. State and Federal programs in the region have expanded incentives for manure incorporation, use of variable rate applications, side-dressing of nutrients, and other production techniques targeted at reducing losses of nutrients from farm fields. As a result, cover crops and nutrient management practices are probably in wider use within the watershed than the CEAP survey shows for 2003–06.

Table 7. Residue and tillage management practices for the baseline conservation condition, Chesapeake Bay region

Residue and tillage management practice in use	Percent of non-HEL	Percent of HEL	Percent of all acres
Acres with carbon gain	43	43	43
Average annual tillage intensity for crop rotation meets criteria for no-till*	25	29	27
Average annual tillage intensity for crop rotation meets criteria for mulch till**	15	12	13
Reduced tillage on some crops in rotation but average annual tillage intensity greater than criteria for mulch till	2	1	1
Continuous conventional tillage in every year of crop rotation***	2	2	2
Acres with carbon loss	57	57	57
Average annual tillage intensity for crop rotation meets criteria for no-till*	21	22	21
Average annual tillage intensity for crop rotation meets criteria for mulch till**	27	26	26
Reduced tillage on some crops in rotation but average annual tillage intensity greater than criteria for mulch till	4	4	4
Continuous conventional tillage in every year of crop rotation***	5	5	5
All acres			
Average annual tillage intensity for crop rotation meets criteria for no-till*	46	51	48
Average annual tillage intensity for crop rotation meets criteria for mulch till**	42	38	40
Reduced tillage on some crops in rotation but average annual tillage intensity greater than criteria for mulch till	5	5	5
Continuous conventional tillage in every year of crop rotation***	7	7	7

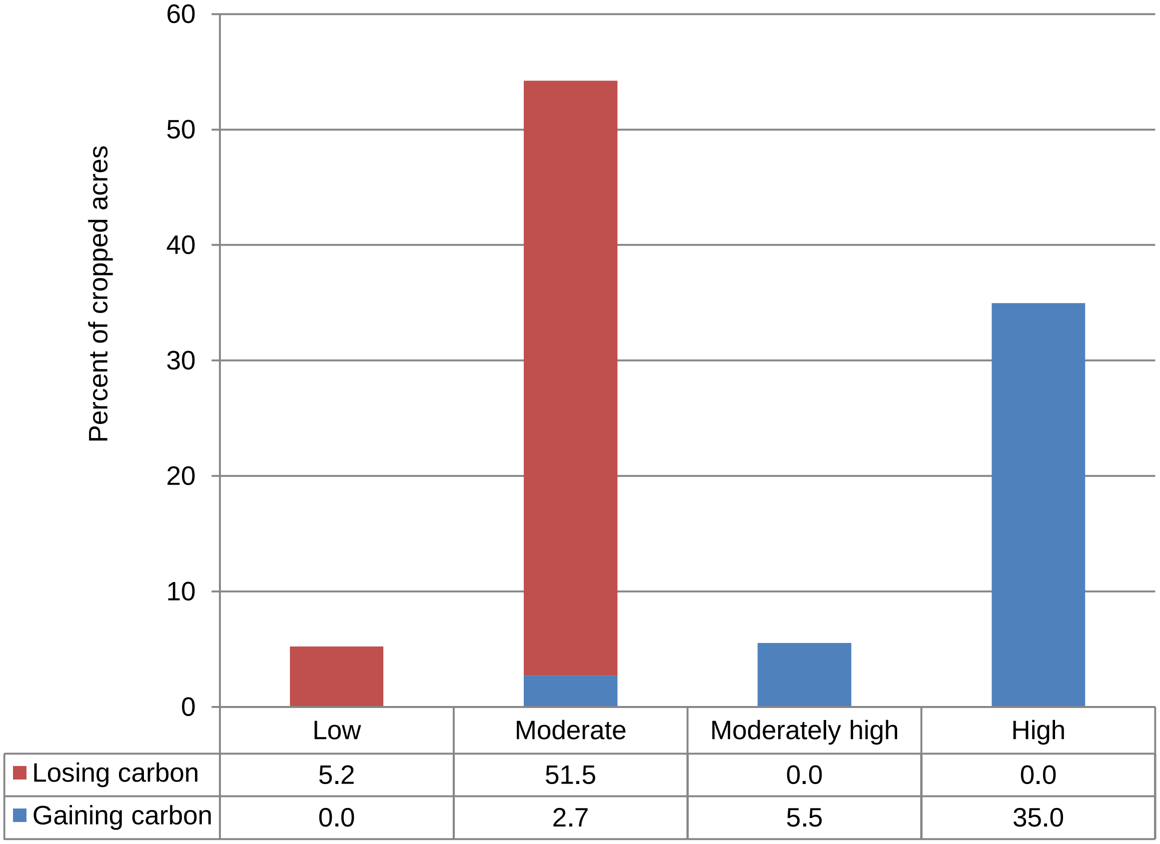
* Average annual Soil Tillage Intensity Rating (STIR) over all crop years in the rotation is less than 30.
** Average annual Soil Tillage Intensity Rating (STIR) over all crop years in the rotation is between 30 and 100.
*** Soil Tillage Intensity Rating (STIR) for every crop year in the rotation is more than 100.
Note: A description of the Soil Tillage Intensity Rating (STIR) can be found at http://stir.nrcs.usda.gov/.
Note: HEL = highly erodible land. About 44 percent of cropped acres in the Chesapeake Bay region are highly erodible land (HEL).
Note: Percents may not add to totals because of rounding.

Table 8. Percent of cropped acres with water erosion control practices for the baseline conservation condition, Chesapeake Bay region

Conservation treatment	Percent of non-HEL	Percent of HEL	Percent of all cropped acres
No-till or mulch till with carbon gain, no structural practices	26	14	21
No-till or mulch till with carbon loss, no structural practices	33	18	26
Some crops with reduced tillage, no structural practices	3	2	2
Structural practices and no-till or mulch till with carbon gain	14	27	19
Structural practices and no-till or mulch till with carbon loss	14	30	21
Structural practices and some crops with reduced tillage	3	2	3
Structural practices only	2	4	3
No water erosion control treatment	5	3	4
All acres	100	100	100

Note: Percents may not add to totals because of rounding.

Figure 8. Conservation treatment levels for residue and tillage management, baseline conservation condition, Chesapeake Bay region



	Low	Moderate	Moderately high	High
🟥 Losing carbon	5.2	51.5	0.0	0.0
🟦 Gaining carbon	0.0	2.7	5.5	35.0

Criteria for four levels of treatment with residue and tillage management are:

- **High treatment**: *All crops* meet tillage intensity criteria for either no-till or mulch till and crop rotation is gaining soil organic carbon.
- **Moderately high treatment**: *Average annual* tillage intensity meets criteria for mulch till or no-till and crop rotation is gaining soil organic carbon; some crops in rotation exceed tillage intensity criteria for mulch till.
- **Moderate treatment**: Some crops have reduced tillage but do not meet criteria for high or moderately high treatment or crop rotation is gaining soil organic carbon; most acres in this treatment level are losing soil organic carbon.
- **Low treatment**: Continuous conventional tillage and crop rotation is losing soil organic carbon.

Conservation Crop Rotation

In the Chesapeake Bay region, crop rotations that meet NRCS criteria (NRCS practice code 328) occur on about 77 percent of the cropped acres. This practice consists of growing different crops in a planned rotation to manage nutrient inputs, enhance soil quality, or reduce soil erosion. Including hay or a close grown crop in the rotation can have a pronounced effect on long-term average field losses of sediment and nutrients, as well as enhancement of soil quality.

The model outputs reported in chapter 4 reflect the benefits of conservation crop rotations. However, the benefits of conservation crop rotation practices could not be assessed in this study for two reasons. First, it was not possible to differentiate conservation crop rotations from crop rotations for other purposes, such as the control of pests or in response to changing markets. Second, the "no-practice scenario" would require simulation of continuous cropping systems. Not only was there inadequate information on chemical use and other farming practices for widespread continuous crop production, but arbitrary decisions about which crops to simulate at each sample point would be required to preserve the level of regional production.

Cover Crops

Cover crops are planted when the principal crops are not growing. The two most important functions of cover crops are (1) to provide soil surface cover and reduce soil erosion, and (2) to utilize and convert excess nutrients remaining in the soil from the preceding crop into plant biomass, thereby reducing nutrient leaching and minimizing the amount of soluble nutrients in runoff during the non-crop growing season. Cover crops also contribute to soil quality by capturing atmospheric carbon in plant tissue and adding it to the soil carbon.

The presence or absence of cover crops was determined from farmer responses in the NRI-CEAP Cropland Survey. The following criteria were used to identify a cover crop.

- A cover crop must be a close-grown crop that is not harvested as a principal crop, or if it is harvested, must have been specifically identified in the NRI-CEAP Cropland Survey as a cover crop as an indicator that the harvest was for an acceptable purpose (such as biomass removal or use as mulch or forage material). [6]
- Spring-planted cover crops are inter-seeded into a growing crop or are followed by the seeding of a summer or late fall crop that may be harvested during that same year or early the next year.
- Late-summer-planted cover crops are followed by the harvest of another crop in the same crop year or the next spring.
- Fall-planted cover crops are followed by the spring planting of a crop for harvest the next year.

Some cover crops are planted for soil protection during establishment of spring crops such as sugar beets and potatoes. Early spring vegetation protects young crop seedlings.

In the Chesapeake Bay region, cover crops were not commonly used as a conservation practice during the period covered by the farmer survey (2003–06). Only about 4 percent of the acres (31 sample points) met the above criteria for a cover crop.

(Since the CEAP survey was conducted, participation in the Maryland Department of Agriculture cover crop program has increased substantially. As a result, cover crops are currently in wider use in Maryland than the CEAP survey shows for 2003–06.)

Irrigation Management Practices

Irrigation in the United States has its roots in the arid West where precipitation is insufficient to meet the needs of growing crops. In other parts of the United States, rainfall totals are sufficient in most years to produce optimum yields of the crops grown. The distribution of the rainfall during the crop growing season, however, is sometimes problematic, especially in years when precipitation is below average. In the Chesapeake Bay region, irrigation applications are sometimes used to supplement natural rainfall.

Irrigation applications are made either with a pressure or a gravity system. Gravity systems, as the name implies, utilizes gravitational energy to move water from higher elevations to lower elevations, such as moving water from a ditch at the head of a field, across the field to the lower end. Pumps are most often used to create the pressure in pressure systems, and the water is applied under pressure through nozzles of one form or another. There are also many variations such as where water is diverted at higher elevations and the pressure created by gravity is substituted for the energy of a pump.

Proper irrigation involves applying appropriate amounts of water to the soil profile to reduce any plant stress while at the same time minimizing water losses through evaporation, deep percolation, and runoff. The conversion of much of the gravity irrigated area to pressure systems and the advent of pressure systems in rain-fed agricultural areas has reduced the volumes of irrigation water lost to deep percolation and end-of-field runoff, but has greatly increased the volume of water lost to evaporation in the sprinkling process. Modern sprinklers utilize improved nozzle technology to increase droplet size as well reduce the contact time from the nozzle to the ground. Irrigation specialists consider the center pivot or linear move sprinkler with low pressure heads as the current state of the art.

About 5 percent of the cropped acres—209,000 acres—receive irrigation water in the Chesapeake Bay region. Irrigation in the region is almost exclusively by pressure systems, however, some 5,300 acres or 2.5 percent of the irrigated area is served by gravity systems. Most common pressure systems are center-pivot or linear-move systems with impact sprinkler heads (43.9 percent) followed by center-pivot or linear-move systems with more efficient low-pressure spray

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[6] Except for the 2003 survey, the questionnaire allowed the respondent to list the purpose for which a crop was grown, including cover crop. This information was not a reliable indicator of a cover crop for conservation purposes for all sample points, based on other information in the survey on crops planted and field operations.

or near-ground emitters (34 percent). Big gun sprinklers make up 9.1 percent. In the Chesapeake Bay region, 80,800 acres (39 percent of the irrigated acres) already have systems with efficiencies at or better than the current state of the art.

Nutrient Management Practices

Nitrogen and phosphorus are essential inputs to profitable crop production. Farmers apply these nutrients to the land as commercial fertilizers and manure to promote plant growth and increase crop yields. Not all of the nutrients applied to the land, however, are taken up by crops; some are lost to the environment and, when combined with naturally occurring levels of these elements or other pollution sources, can create offsite water quality problems.

Sound nutrient management systems can minimize nutrient losses from the agricultural management zone while providing adequate soil fertility and nutrient availability to ensure realistic yields. (The agricultural management zone is defined as the zone surrounding a field that is bounded by the bottom of the root zone, edge of the field, and top of the crop canopy.) Such systems are tailored to address the specific cropping system, nutrient sources available, and site characteristics of each field. Nutrient management systems have four basic criteria for application of commercial fertilizers and manure.

1. Apply nutrients at the **appropriate rate** based on soil and plant tissue analyses and realistic yield goals.
2. Apply the **appropriate form** of fertilizer and organic material with compositions and characteristics that resist nutrient losses from the agricultural management zone.
3. Apply at the **appropriate time** to supply nutrients to the crop when the plants have the most active uptake and biomass production, and avoid times when adverse weather conditions can result in large losses of nutrients from the agricultural management zone.
4. Apply using the **appropriate application method** that provides nutrients to the plants for rapid, efficient uptake and reduces the exposure of nutrient material to forces of wind and water.

Depending on the field characteristics, these nutrient management techniques can be coupled with other conservation practices such as conservation crop rotations, cover crops, residue management practices, and structural practices to minimize the potential for nutrient losses from the agricultural management zone. Even though nutrient transport and losses from agricultural fields cannot be completely eliminated, they can be minimized by careful management and kept within an acceptable level.

The presence or absence of nutrient management practices was based on information on the timing, rate, and method of application for manure and commercial fertilizer as reported by the producer in the NRI-CEAP Cropland Survey. The appropriate form of nutrients applied was not evaluated because the survey was not sufficiently specific about the material formulations that were applied. The following criteria were used to identify the appropriate rate, time, and method of nutrient application for each crop or crop rotation.

- All commercial fertilizer and manure applications are within 3 weeks prior to plant date, at planting, or within 60 days after planting.
- The method of application for commercial fertilizer or manure is some form of incorporation or banding or spot treatment or foliar applied.
- The rate of nitrogen application, including the sum of both commercial fertilizer and manure nitrogen available for crops in the year of application, is—
  - less than 1.4 times the amount of nitrogen removed in the crop yield at harvest for *each* crop, except for cotton and small grain crops;
  - less than 1.6 times the amount of nitrogen removed in the crop yield at harvest for small grain crops (wheat, barley, oats, rice, rye, buckwheat, emmer, spelt, and triticale);
  - less than 60 pounds of nitrogen per bale of cotton harvested.
- The rate of phosphorus application summed over all applications and crops in the rotation, including both commercial fertilizer and manure phosphorus, is less than 1.1 times the amount of phosphorus removed in the crop yields at harvest summed over all crops in the rotation.

Phosphorus application rate criteria apply to the *full crop rotation* to account for infrequent applications intended to provide phosphorus for multiple crops or crop years, which is often the case with manure applications. Nitrogen application rate criteria apply to *each* crop in the rotation.

Criteria used here to identify the occurrence of nutrient management practices, while consistent with NRCS standards, do not necessarily represent the best possible set of nutrient management practices. These nutrient management criteria are intended to represent practice recommendations commonly found in comprehensive nutrient management conservation plans.

As shown in table 9, the majority of acres in the Chesapeake Bay region meet one or more of the criteria for nutrient management:

- 73 percent of cropped acres meet criteria for timing of nitrogen applications for one or more crops and 76 percent meet criteria for timing of phosphorus applications for one or more crops;
- 88 percent of cropped acres meet criteria for method of nitrogen application for one or more crops and 92 percent meet criteria for method of phosphorus application for one or more crops;
- 88 percent of cropped acres meet criteria for nitrogen application rate for one or more crops;
- 3 percent of cropped acres have no nitrogen applied and 1 percent have no phosphorus applied.

Table 9. Nutrient management practices for the baseline conservation condition, Chesapeake Bay region

	Percent of acres without manure applied	Percent of acres with manure applied	Percent of all cropped acres
Nitrogen*			
No N applied to any crop in rotation	4	0	3
For samples where N is applied:			
Time of application			
All crops in rotation have application of N (manure and/or fertilizer) within 3 weeks before planting or after planting	77	16	54
Some but not all crops have application of N (manure and/or fertilizer) within 3 weeks before planting or after planting	8	36	19
No crops in rotation have application of N (manure and/or fertilizer) within 3 weeks before planting or after planting	10	48	24
Method of application			
All crops in rotation have N applied with incorporation or banding/foliar/spot treatment	37	32	35
Some but not all crops in rotation have N applied with incorporation or banding/foliar/spot treatment	45	67	53
No crops in rotation have N applied with incorporation or banding/foliar/spot treatment	14	0	9
Rate of application			
All crops in rotation meet the nitrogen rate criteria described in text	39	30	35
Some but not all crops in rotation meet the nitrogen rate criteria described in text	51	57	53
No crops in rotation meet the nitrogen rate criteria described in text	6	13	9
Timing and method and rate of application			
All crops meet the nitrogen rate criteria described in text and application within 3 weeks before planting or after planting with incorporation or banding/foliar/spot treatment	18	3	13
Some but not all crops meet the nitrogen rate criteria described in text or application within 3 weeks before planting or after planting or use of incorporation or banding/foliar/spot treatment	56	63	59
No crops meet the nitrogen rate criteria described in text or application within 3 weeks before planting or after planting or use of incorporation or banding/foliar/spot treatment	21	34	26
Phosphorus*			
No P applied to any crop in rotation	1	0	1
For samples where P is applied:			
Time of application			
All crops in rotation have application of P (manure and/or fertilizer) within 3 weeks before planting or after planting	82	17	58
Some but not all crops have application of P (manure and/or fertilizer) within 3 weeks before planting or after planting	8	36	18
No crops in rotation have application of P (manure and/or fertilizer) within 3 weeks before planting or after planting	9	47	23
Method of application			
All crops in rotation have P applied with incorporation or banding/foliar/spot treatment	49	47	49
Some but not all crops in rotation have P applied with incorporation or banding/foliar/spot treatment	37	53	43
No crops in rotation have P applied with incorporation or banding/foliar/spot treatment	12	0	7
Rate of application			
Crop rotation has P applied at a rate less than 1.1 times the removal of P in the yield at harvest for the crop rotation	48	19	37
Crop rotation has P applied at a rate more than 1.1 times the removal of P in the yield at harvest for the crop rotation	50	81	62
Timing and method and rate of application			
Crop rotation has P rate less than 1.1 times removal at harvest and applications within 3 weeks before planting or after planting with incorporation or banding/foliar/spot treatment	26	2	17
Crop rotation has P rate less than 1.1 times removal at harvest and some crops had application within 3 weeks before planting or after planting and/or some crops used incorporation or banding/foliar/spot treatment	19	12	17
Crop rotation has P rate more than 1.1 times removal at harvest and no crops had applications within 3 weeks before planting or after planting and no crops used incorporation or banding/foliar/spot treatment	54	85	66
Nitrogen and Phosphorus			
Crop rotation P rate less than 1.1 and N rate criteria described in text and all applications within 3 weeks before planting or after planting with incorporation or banding/foliar/spot treatment, including acres with no N or P applied	14	1	9
Crop rotation P rate less than 1.1 and N rate criteria appropriate for full conservation treatment (see text) and all application within 3 weeks before planting or after planting with incorporation or banding/foliar/spot treatment , including acres with no N or P applied	9	1	6
All sample points	100	100	100

Note: About 38 percent of cropped acres (1.6 million acres) have manure applied. Percents may not add to 100 because of rounding.

* These estimates include adjustments made to the reported data on nitrogen and phosphorus application rates from the survey because of missing data and data-entry errors. In the case of phosphorus, the 3-year data period for which information was reported was too short to pick up phosphorus applications made at 4- and 5-year intervals between applications, which is a common practice for producers adhering to sound phosphorus management techniques. Since crop growth, and thus canopy development which decreases erosion, is a function of nitrogen and phosphorus, it was necessary to add additional nitrogen and phosphorus when the reported levels were insufficient to support reasonable crop yields throughout the 47 years in the model simulation. The approach taken was to first identify crop samples that have application rates recorded erroneously or were under-reported in the survey. The model was used to identify these samples by running the simulation at optimal levels of nitrogen and phosphorus for crop growth. The set of crop samples identified were treated as if they had missing data. Additional nitrogen or phosphorus was added to these crop samples so that the total nitrogen or phosphorus use was similar to that for the unadjusted set of crop samples. About 29 percent of the acres received a nitrogen adjustment for one or more crops. About 26 percent of the acres received a phosphorus adjustment for one or more crops. Nitrogen and phosphorus were added by increasing the existing applications (thus preserving the reported timing and methods), when present, or were applied at plant. (For additional information on adjustment of nutrient application rates, see “Adjustment of CEAP Cropland Survey Nutrient Application Rates for APEX Modeling,” available at http://www.nrcs.usda.gov/technical/nri/ceap/Cropland.html

Fewer acres, however, meet criteria for all crops in the rotation:

- 54 percent of cropped acres meet criteria for timing of nitrogen applications on all crops and 58 percent meet criteria for timing of phosphorus applications on all crops.
- 35 percent of cropped acres meet criteria for method of nitrogen application on all crops and 49 percent meet criteria for method of phosphorus application on all crops.
- 35 percent of cropped acres meet criteria for nitrogen application rate on all crops and 37 percent meet criteria for phosphorus application rates for the full crop rotation.

Acres with manure applied—about 38 percent of cropped acres—generally meet the criteria for method of application at about the same frequency as acres with only commercial fertilizer applications. Criteria for timing and rate, however, are met less frequently for acres receiving manure:

- 16 percent of cropped acres receiving manure meet criteria for timing of nitrogen applications on all crops, compared to 77 percent for acres not receiving manure;
- 17 percent of cropped acres receiving manure meet criteria for timing of phosphorus applications on all crops, compared to 82 percent for acres not receiving manure;
- 30 percent of cropped acres receiving manure meet criteria for nitrogen application rates on all crops, compared to 39 percent for acres not receiving manure;
- 19 percent of cropped acres receiving manure meet criteria for phosphorus application rates, compared to 48 percent for acres not receiving manure.

Overall, few acres meet all nutrient management criteria:

- only 13 percent of the acres meet all criteria for nitrogen applications, while another 3 percent of cropped acres have no nitrogen applied;
- only17 percent of the acres meet all criteria for phosphorus applications, while another 1 percent of the acres have no phosphorus applied;
- only 9 percent of cropped acres meet criteria for *both* phosphorus and nitrogen management (table 9), including acres not receiving nutrient applications.

Lower nitrogen rate criteria are appropriate for acres that meet application timing and method criteria and also are fully treated for soil erosion control because more of the nitrogen applied is retained on the field and is therefore available for crop growth. In the simulation of additional soil erosion control and nutrient management (full treatment) in chapter 6, the rates of nitrogen application, including both commercial fertilizer and manure nitrogen, were proportionately reduced to the following levels—

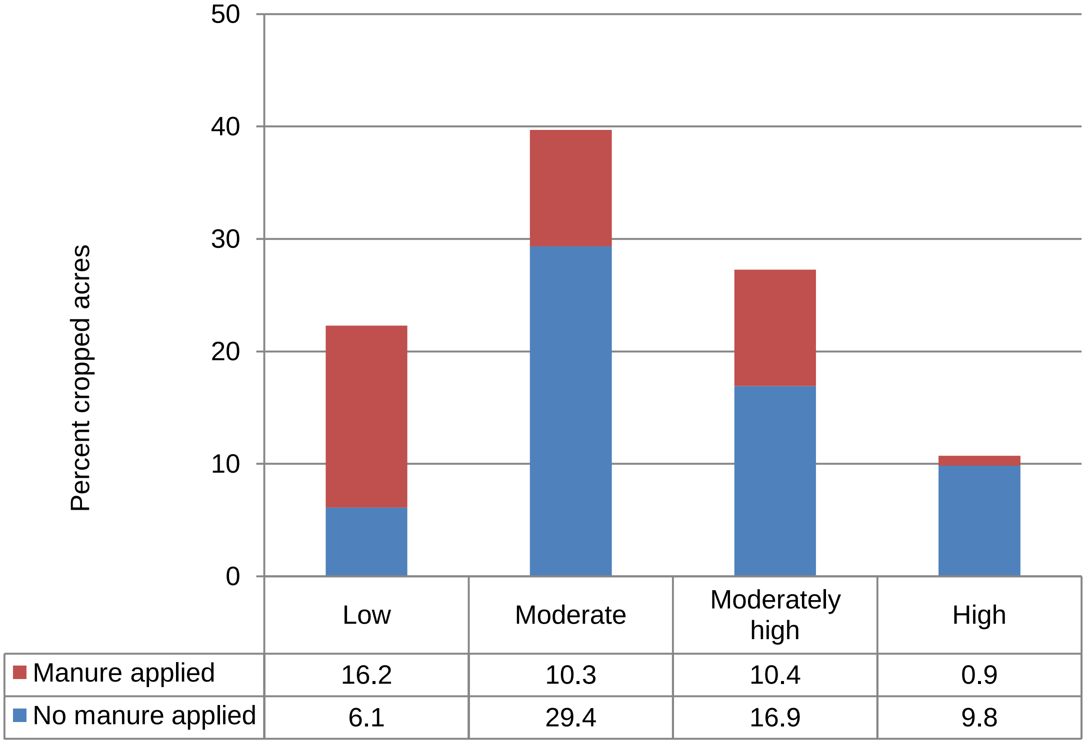
- 1.2 times the amount of nitrogen removed in the crop yield at harvest for *each* crop, except for cotton and small grain crops;
- 1.5 times the amount of nitrogen removed in the crop yield at harvest for small grain crops; and
- 50 pounds of nitrogen per bale of cotton harvested.

As shown in table 9, only 6 percent of cropped acres in the region meet *all* nutrient management criteria including these lower nitrogen rate criteria and including acres not receiving nutrient applications.

Four levels of treatment for nitrogen and phosphorus management were derived for use in evaluating the adequacy of nutrient management. These treatment levels are combined with soil risk classes to estimate acres that appear to be under-treated in chapter 5. Criteria for the treatment levels are presented in figures 9 and 10. The high treatment level represents consistent use of appropriate rate, timing, and method for all crops, including the lower nitrogen application rate criteria appropriate for full conservation treatment conditions.

Based on these treatment levels, about 11 percent of the acres in the Chesapeake Bay region have a high level of nitrogen management and about 18 percent have a high level of phosphorus management (figs. 9 and 10). Few acres with manure applied meet the criteria for the high treatment levels. About 22 percent of cropped acres have a low level of nitrogen management and 48 percent of the acres have a low level of phosphorus management.

Figure 9. Conservation treatment levels for nitrogen management, baseline conservation condition, Chesapeake Bay region

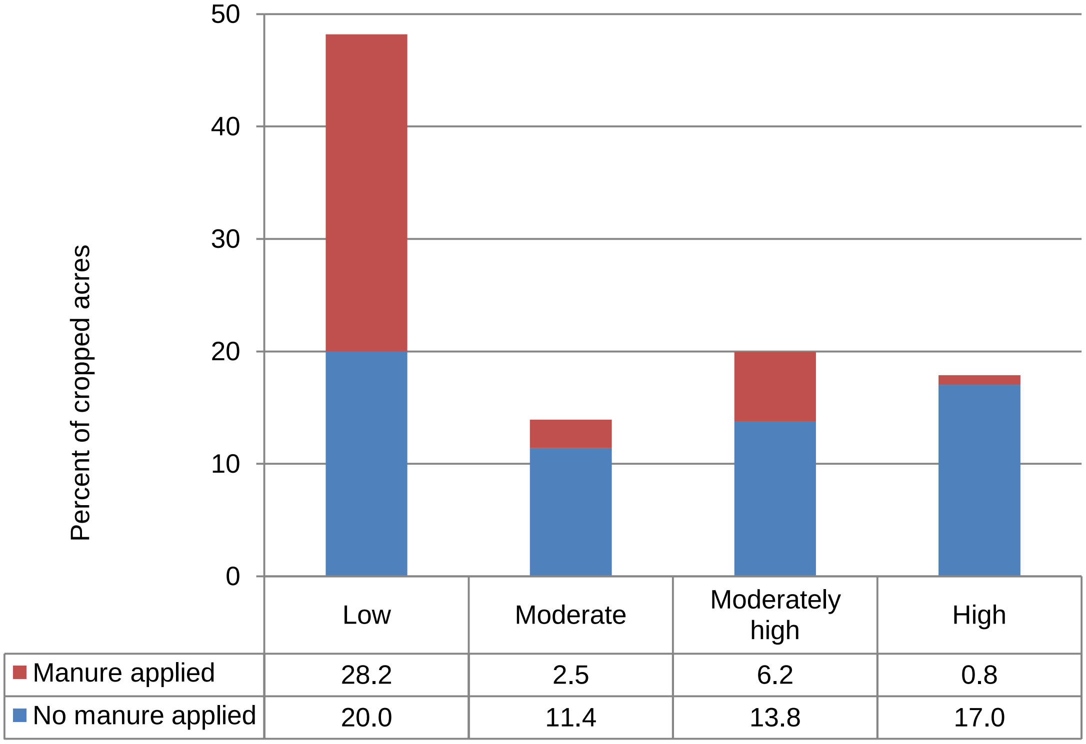


	Low	Moderate	Moderately high	High
🟥 Manure applied	16.2	10.3	10.4	0.9
🟦 No manure applied	6.1	29.4	16.9	9.8

Criteria for four levels of nitrogen management are:

- **High treatment**: All crops have: (1) total nitrogen application rates (including manure) less than 1.2 times the nitrogen in the crop yield for crops other than cotton and small grains, less than 1.5 times the nitrogen in the crop yield for small grains, and less than 50 pounds of nitrogen applied per cotton bale; (2) all applications occur within 3 weeks before planting or after planting; and (3) all applications are incorporated or banding/foliar/spot treatment is used.
- **Moderately high treatment**: All crops have total nitrogen application rates (including manure) less than 1.4 times the nitrogen in the crop yield for crops other than cotton and small grains, less than 1.6 times the nitrogen in the crop yield for small grains, and less than 60 pounds of nitrogen applied per cotton bale for all crops. Timing and method of application criteria may or may not be met.
- **Moderate treatment**: All crops meet either the above criteria for timing *or* method, but do not meet criteria for rate.
- **Low treatment**: Some or all crops in rotation exceed criteria for rate and either timing or method.

Figure 10. Conservation treatment levels for phosphorus management, baseline conservation condition, Chesapeake Bay region



	Low	Moderate	Moderately high	High
🟥 Manure applied	28.2	2.5	6.2	0.8
🟦 No manure applied	20.0	11.4	13.8	17.0

Criteria for four levels of phosphorus management are:

- **High treatment**: (1) total phosphorus application rates (including manure) summed over all crops are less than 1.1 times the phosphorus in the crop yields for the crop rotation, (2) all applications occur within 3 weeks before planting or after planting, and (3) all applications are incorporated or banding/foliar/spot treatment was used. (Note that phosphorus applications for individual crops could exceed 1.1 times the phosphorus in the crop yield but total applications for the crop rotation could not.)
- **Moderately high treatment**: Total phosphorus application rates (including manure) are less than 1.1 times the phosphorus in the crop yield for the crop rotation. No application rate or timing of application criteria is applied.
- **Moderate treatment**: Sample points that do not meet the high or moderately high criteria but all phosphorus applications for all crops have appropriate time *and* method of application.
- **Low treatment**: All acres have excessive application rates over the crop rotation and inadequate method or timing of application for at least one crop in the rotation.

Pesticide Management Practices

The presence or absence of pesticide management practices was based on an Integrated Pest Management (IPM) indicator developed using producer responses to the set of IPM-related questions in the NRI-CEAP Cropland Survey (table 10).[7]

Adoption of IPM systems normally occurs along a continuum from largely reliant on prophylactic control measures and pesticides to multiple-strategy, biologically intensive approaches, and is not usually an either/or situation. The practice of IPM is site-specific in nature, with individual tactics determined by the particular crop/pest/environment scenario. Where appropriate, each site should have in place a management strategy for **Prevention, Avoidance, Monitoring,** and **Suppression** of pest populations (the **PAMS** approach) (Coble 1998). In order to qualify as IPM practitioners, growers would use tactics in all four PAMS components.

Prevention is the practice of keeping a pest population from infesting a field or site, and should be the first line of defense. It includes such tactics as using pest-free seeds and transplants, preventing weeds from reproducing, irrigation scheduling to avoid situations conducive to disease development, cleaning tillage and harvesting equipment between fields or operations, using field sanitation procedures, and eliminating alternate hosts or sites for insect pests and disease organisms.

Avoidance may be practiced when pest populations exist in a field or site but the impact of the pest on the crop can be avoided through some cultural practice. Examples of avoidance tactics include crop rotation in which the crop of choice is not a host for the pest, choosing cultivars with genetic resistance to pests, using trap crops or pheromone traps, choosing cultivars with maturity dates that may allow harvest before pest populations develop, fertilization programs to promote rapid crop development, and simply not planting certain areas of fields where pest populations are likely to cause crop failure.

Monitoring and proper identification of pests through surveys or scouting programs, including trapping, weather monitoring and soil testing where appropriate, are performed as the basis for suppression activities. Records are kept of pest incidence and distribution for each field or site. Such records form the basis for crop rotation selection, economic thresholds, and suppressive actions.

Suppression of pest populations may be necessary to avoid economic loss if prevention and avoidance tactics are not successful. Suppressive tactics include *cultural* practices such as narrow row spacing or optimized in-row plant populations, alternative tillage approaches such as no-till or strip-till systems, cover crops or mulches, or using crops with allelopathic potential in the rotation. *Physical* suppression tactics include cultivation or mowing for weed control, baited or pheromone traps for certain insects, and temperature management or exclusion devices for insect and disease management. *Biological* controls, including mating disruption for insects, are alternatives to conventional pesticides, especially where long-term control of a troublesome pest species can be attained. Naturally occurring biological controls exist, where they exist, are important IPM tools. *Chemical pesticides* are applied as a last resort in suppression systems using a sound management approach, including selection of pesticides with low risk to non-target organisms.

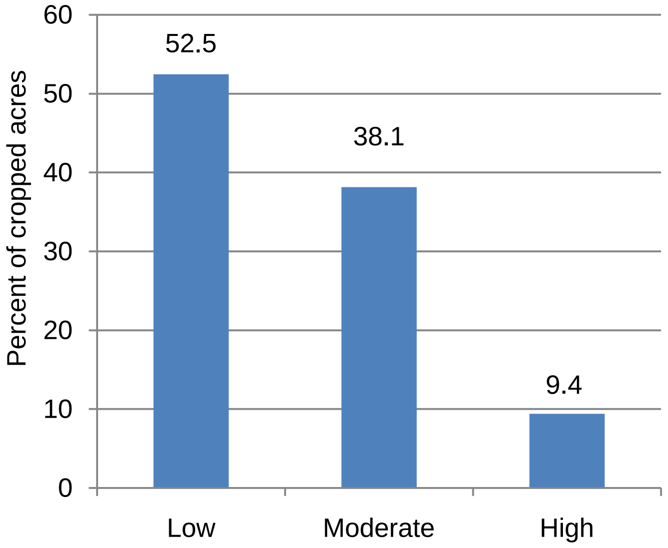
An IPM index was developed to determine the level of IPM activity for each sample point. The index was constructed as follows.

- Scores were assigned to each question by a group of IPM experts.
- Scores for each PAMS category were normalized to have a maximum score of 100.
- The four PAMS categories were also scored in terms of relative importance for an IPM index: prevention = 1/6, avoidance = 1/6, monitoring = 1/3, and suppression = 1/3.
- The IPM indicator was calculated by multiplying the normalized PAMS category by the category weight and summing over the categories.

An IPM indicator score greater than 60 defined sample points with a high level of IPM activity. Sample points with an IPM indicator score of 35 to 60 were classified as moderately high IPM treatment and sample points with an IPM score less than 35 were classified as low IPM treatment.

About 9 percent of the acres in the Chesapeake Bay region have a high level of IPM activity (fig. 11). About 38 percent have a moderate level of IPM activity, and 53 percent have a low level of IPM activity.

Figure 11. Integrated Pesticide Management indicator for the baseline conservation condition, Chesapeake Bay region



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[7] For a full documentation of the derivation of the IPM indicator, see "Integrated Pest Management (IPM) Indicator Used in the CEAP Cropland Modeling," available at http://www.nrcs.usda.gov/technical/nri/ceap/Cropland.html.

Table 10. Summary of survey responses to pest management questions, Chesapeake Bay region

Survey question*	Number samples with “yes” response	Percent of cropped acres
Prevention		
Pesticides with different action rotated or tank mixed to prevent resistance	252	33
Plow down crop residues	133	20
Chop, spray, mow, plow, burn field edges, etc.	264	33
Clean field implements after use	272	35
Remove crop residue from field	72	10
Water management used to manage pests (irrigated samples only)	12	1
Avoidance		
Rotate crops to manage pests	531	66
Use minimum till or no-till to manage pests	482	56
Choose crop variety that is resistant to pests	299	34
Planting locations selected to avoid pests	109	12
Plant/harvest dates adjusted to manage pests	53	6
Monitoring		
Scouting practice: general observations while performing routine tasks	278	36
Scouting practice: deliberate scouting	366	44
--Established scouting practice used	156	19
--Scouting due to pest development model	62	8
--Scouting due to pest advisory warning	99	9
Scouting done by: (only highest of the 4 scores is used)		
--Scouting by operator	221	27
--Scouting by employee	2	<1
--Scouting by chemical dealer	86	10
--Scouting by crop consultant or commercial scout	63	7
Scouting records kept to track pests?	140	17
Scouting data compared to published thresholds?	221	26
Diagnostic lab identified pest?	58	6
Weather a factor in timing of pest management practice	250	31
Suppression		
Pesticides used?	747	94
Weather data used to guide pesticide application	479	60
Biological pesticides or products applied to manage pests	87	9
Pesticides with different mode of action rotated or tank mixed to prevent resistance	252	33
Pesticide application decision factor (one choice only):		
--Routine treatments or preventative scheduling	393	50
--Comparison of scouting data to published thresholds	67	8
--Comparison of scouting data to operator's thresholds	71	8
--Field mapping or GPS	2	0
--Dealer recommendations	112	13
--Crop consultant recommendations	54	8
--University extension recommendations	5	1
--Neighbor recommendations	1	<1
--"Other"	13	2
Maintain ground covers, mulch, or other physical barriers	317	41
Adjust spacing, plant density, or row directions	153	16
Release beneficial organisms	13	1
Cultivate for weed control during the growing season	42	6
Number of respondents	771	100

Note: The scores shown in this table were used to develop an IPM indicator as discussed in the text.

Conservation Cover Establishment

Establishing long-term cover of grass, forbs, or trees on a site provides the maximum protection against soil erosion. Conservation cover establishment is often used on cropland with soils that are vulnerable to erosion or leaching. The practice is also effective for sites that are adjacent to waterways, ponds, and lakes. Because these covers do not require annual applications of fertilizer and pesticides, this long-term conserving cover practice greatly reduces the loss of nitrogen and phosphorus from the site, and nearly eliminates pesticide loss. Because conservation covers are not harvested, they generate organic material that decomposes and increases soil organic carbon. For this study, the effect of a long-term conserving cover practice was estimated using acres enrolled in the General Signup of the CRP. The CRP General Signup is a voluntary program in which producers with eligible land enter into 10- to 15-year contracts to establish long-term cover to reduce soil erosion, improve water quality, and enhance wildlife habitat.

Landowners receive annual rental payments and cost-share assistance for establishing and maintaining permanent vegetative cover. To be eligible for enrollment in the CRP General Signup, the field (or tract) must meet specified crop history criteria.

Other factors governing enrollment in the CRP include natural resource-based eligibility criteria, an Environmental Benefits Index (EBI) used to compare and rank enrollment offers, acreage limits, and upper limits on the proportion of a county's cropland that can be enrolled (USDA Farm Service Agency 2004; Wiebe and Gollehon 2006). Initially, the eligibility criteria included only soil erosion rates and inherent soil erodibility. During the 1990s and to date, the eligibility criteria have continued to evolve, with increasing emphasis placed on issues other than soil erodibility. For contract offer ranking, weight was given to proposals that also benefited wildlife, air and water quality, and other environmental concerns.

As of 2003, about 31.5 million acres were enrolled in the CRP General Signup nationally, including about 100,000 in the Chesapeake Bay region (USDA/NRCS 2007). Approximately two-thirds of the cropland acres enrolled in the CRP in the Chesapeake Bay region is classified as highly erodible land. The inclusion of non-highly erodible land is due to both the expansion of enrollment eligibility criteria beyond soil erosion issues and the fact that farmers were allowed to enroll entire fields in the CRP if a specified portion of the field (varied by signup and eligibility criterion) met the criteria.

In the Chesapeake Bay region, 65 percent of the CRP land is planted to introduced grasses, 29 percent to trees, 5 percent to wildlife habitat and 1 percent to native grasses. The plantings designated in the NRI database for each sample point were simulated in the model. However, in all cases the simulated cover was a mix of species and all points included at least one grass and one clover species.

In addition to the General CRP Signup, cultivated cropland acres (whole field) can also be enrolled in long-term conserving cover under the Conservation Reserve Enhancement Program (CREP). The Maryland Department of Agriculture reports that CREP acreage enrollment outpaces CRP General Signup in that state by 11 to 1 because CREP is better suited to regional conditions and provides better incentive rates than CRP. The Farm Service Agency estimates that about an additional 100,000 acres of land in long-term conserving cover have been enrolled in CREP throughout the Chesapeake Bay region (Alex Barbarika, USDA/FSA, personal communication).

These additional acres of land in long-term conserving cover could not be included in the assessment of the effects of conservation practices because the acreage is not represented in the NRI, which is the source of information on soils, slopes, and cover types required to simulate fate and transport of sediment and nutrients.

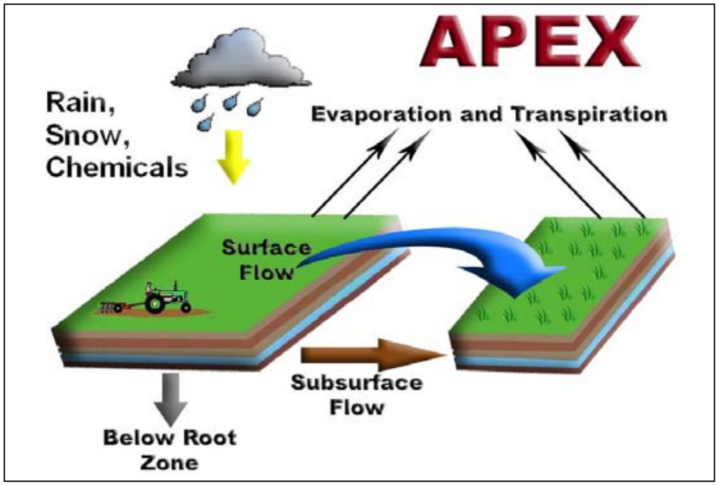
Chapter 4
Onsite (Field-Level) Effects of Conservation Practices

The Field-Level Cropland Model—APEX

A physical process model called APEX was used to simulate the effects of conservation practices at the field level (Williams et al. 2006; Williams et al. 2008; Gassman et al. 2009 and 2010).[8] The I_APEX model run management software developed at the Center for Agricultural and Rural Development, Iowa State University, was used to perform the simulations in batch mode.[9]

The APEX model is a field-scale, daily time-step model that simulates weather, farming operations, crop growth and yield, and the movement of water, soil, carbon, nutrients, sediment, and pesticides (fig. 12). The APEX model and its predecessor, EPIC (Environmental Policy Impact Calculator), have a long history of use in simulation of agricultural and environmental processes and of the effect of agricultural technology and government policy (Izaurralde et al. 2006;Williams 1990; Williams et al. 1984; Gassman et al. 2005).[10]

Figure 12. Daily hydrologic processes simulated by APEX



On a daily basis, APEX simulates the farming operations used to grow crops, such as planting, tillage before and after planting, application of nutrients and pesticides, application of manure, irrigation, and harvest. Weather events and their interaction with crop cover and soil properties are simulated; these events affect crop growth and the fate and transport of water and chemicals through the soil profile and over land to the edge of the field. Over time, the chemical makeup and physical structure of the soil may change, which in turn affect crop yields and environmental outcomes. Crop residue remaining on the field after harvest is transformed into organic matter. Organic matter may build up in the soil over time, or it may degrade.

APEX simulates all of the basic biological, chemical, hydrological, and meteorological processes of farming systems and their interactions. Soil erosion is simulated over time, including wind erosion, sheet and rill erosion, and the loss of sediment beyond the edge of the field. The nitrogen, phosphorus, and carbon cycles are simulated, including chemical transformations in the soil that affect their availability for plant growth or for transport from the field. Exchange of gaseous forms between the soil and the atmosphere is simulated, including losses of gaseous nitrogen compounds.

The NRI-CEAP Cropland Survey was the primary source of information on all farming activities simulated using APEX. Crop data were transformed for the model into a crop rotation for each sample point, which was then repeated over the 47-year simulation. The 3 years of data reported in the survey were represented in the model simulation as 1-, 2-, 3-, 4-, or 5-year crop rotations. For example, a 2-year corn-soybean rotation was used if the operator reported that corn was grown in the first year, soybeans in the second year, and corn again in the third year. In this case, only 2 of the reported 3 years of survey data were used. If management differed significantly for the 2 years that corn was grown (manure was applied, for example, or tillage was different), the rotation was expanded to 4 years, retaining the second year of corn and repeating the year of soybeans. In addition, some rotations with alfalfa or grass seed were simulated as 5-year rotations. Specific rules and procedures were established for using survey data to simulate cover crops, double crops, complex systems such as intercropping and nurse crops, perennial hay in rotations, abandoned crops, re-planting, multiple harvests, manure applications, irrigation, and grazing of cropland before and after harvest.[11]

Use of conservation practices in the Chesapeake Bay region was obtained from four sources: (1) NRI-CEAP Cropland Survey, (2) NRCS field offices, (3) USDA Farm Service Agency (FSA), and (4) the 2003 NRI. For each sample point, data from these four sources were pooled and duplicate practices discarded.[12]

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[8] The full theoretical and technical documentation of APEX can be found at http://epicapex.brc.tamus.edu/downloads/user-manuals.aspx.

[9] The I_APEX software steps through the simulations one at a time, extracting the needed data from the Access input tables, executes APEX, and then stores the model output in Access output files. The Web site for that software is http://www.card.iastate.edu/environment/interactive_programs.aspx.

[10] Summaries of APEX model validation studies on how well APEX simulates measured data are presented in Gassman et al. (2009) and in "APEX Model Validation for CEAP" found at http://www.nrcs.usda.gov/technical/nri/ceap/Cropland.html.

[11] For a detailed description of the rules and procedures, see "Transforming Survey Data to APEX Model Input Files," http://www.nrcs.usda.gov/technical/nri/ceap/Cropland.html.

[12] For a detailed description of the rules and procedures for simulation of structural conservation practices, see "Modeling Structural Conservation Practices in APEX," http://www.nrcs.usda.gov/technical/nri/ceap/Cropland.html.

Simulating the No-Practice Scenario

The purpose of the no-practice scenario is to provide an estimate of sediment, nutrient, and pesticide loss from farm fields under conditions without the use of conservation practices. The benefits of conservation practices in use within the Chesapeake Bay region were estimated by contrasting model output from the no-practice scenario to model output from the baseline conservation condition (2003–06). The only difference between the no-practice scenario and the baseline conservation condition is that the conservation practices are removed or their effects are reversed in the no-practice scenario simulations. There were usually several alternatives that could be used to represent "no practices." The no-practice representations derived for use in this study conformed to the following guidelines.

- **Consistency:** It is impossible to determine what an individual farmer would be doing if he or she had not adopted certain practices, so it is important to represent all practices on all sample points in a consistent manner that is based on the intended purpose of each practice.

- **Simplicity:** Complex rules for assigning "no-practice" activities lead to complex explanations that are difficult to substantiate and sometimes difficult to explain and accept. Complexity would not only complicate the modeling process but also hamper the interpretation of results.

- **Historical context avoided:** The no-practice scenario is a technological step backward for conservation, not a chronological step back to a prior era when conservation practices were not used. Although the advent of certain conservation technologies can be dated, the adoption of technology is gradual, regionally diverse, and ongoing. It is also important to retain the overall crop mix in the region, as it in part reflects today's market forces. Therefore, moving the clock back to 1950s (or any other time period) agriculture is not the goal of the no-practice scenario. Taking away the conservation ethic is the goal.

- **Moderation:** The no-practice scenario should provide a reasonable level of "poor" conservation so that a believable benefit can be determined, where warranted, but not so severe as to generate exaggerated conservation gains by simulating the worst-case condition. Tremendous benefits could be generated if, for example, nutrients were applied at twice the recommended rates with poor timing or application methods in the no-practice simulation. Similarly, large erosion benefits could be calculated if the no-practice representation for tillage was fall plowing with moldboard plows and heavy disking, which was once common but today would generally be considered economically inefficient.

- **Maintenance of crop yield or efficacy**. It is impossible to avoid small changes in crop yields, but care was taken to avoid no-practice representations that would significantly change crop yields and regional production capabilities. The same guideline was followed for pest control—the suite of pesticides used was not adjusted in the no-practice scenario because of the likelihood that alternative pesticides would not be as effective and would result in lower yields under actual conditions.

A deliberate effort was made to adhere to these guidelines to the same degree for all conservation practices so that the overall level of representation would be equally moderate for all practices.

Table 11 summarizes the adjustments to conservation practices used in simulation of the no-practice scenario.

No-practice representation of structural practices

The no-practice field condition for structural practices is simply the removal of the structural practices from the modeling process. In addition, the soil condition is changed from "Good" to "Poor" for the determination of the runoff curve number for erosion prediction.

Overland flow. This group includes such practices as terraces and contouring which slow the flow of water across the field. For the practices affecting overland flow of water and therefore the P factor of the USLE-based equations, the P factor was increased to 1. Slope length is also changed for practices such as terraces to reflect the absence of these slope-interrupting practices.

Concentrated flow. This group of practices is designed to address channelized flow and includes grassed waterways and grade stabilization structures. These practices are designed to prevent areas of concentrated flow from developing gullies or to stabilize gullies that have developed. The no-practice protocol for these practices removes the structure or waterway and replaces it with a "ditch" as a separate subarea. This ditch, or channel, represents a gully; however, the only sediment contributions from the gully will come from downcutting. Headcutting and sloughing of the sides are not simulated in APEX.

Edge of field. These practices include buffers, filters, and other practices that occur outside the primary production area and act to mitigate the losses from the field. The no-practice protocol removes these areas and their management. When the practices are removed, the slope length is also restored to the undisturbed length that it would be if the practices were not in place. (When simulating a buffer in APEX, the slope length reported in the NRI is adjusted.)

Wind control. Practices such as windbreaks or shelterbelts, cross wind ridges, stripcropping or trap strips, and hedgerows are examples of practices used for wind control. The unsheltered distance reflects the dimensions of the field as modeled, 400 meters or 1,312 feet. Any practices reducing the unsheltered distance are removed and the unsheltered distance set to 400 meters.

Table 11. Construction of the no-practice scenario for the Chesapeake Bay region

Practice adjusted	Criteria used to determine if a practice was in use	Adjustment made to create the no-practice scenario
Structural practices	1. Overland flow practices present 2. Concentrated flow—managed structures or waterways present 3. Edge-of-field mitigation practices present 4. Wind erosion control practices present	1. USLE P-factor changed to 1 and slope length increased for points with terraces, soil condition changed from good to poor. 2. Structures and waterways replaced with earthen ditch, soil condition changed from good to poor. 3. Removed practice and width added back to field slope length. 4. Unsheltered distance increased to 400 meters
Residue and tillage management	STIR ≤100 for any crop within a crop year	Add two tandem diskings 1 week prior to planting
Cover crop	Cover crop planted for off-season protection	Remove cover crop simulation (field operations, fertilizer, grazing, etc.)
Irrigation	Pressure systems	Change to hand-move sprinkler system except where the existing system is less efficient
Nitrogen rate	Total of all applications of nitrogen (commercial fertilizer and manure applications) ≤1.4 times harvest removal for non-legume crops, except for cotton and small grain crops	Increase rate to 1.98 times harvest removal (proportionate increase in all reported applications, including manure)
	Total of all applications of nitrogen (commercial fertilizer and manure applications) ≤1.6 times harvest removal for small grain crops	Increase rate to 2.0 times harvest removal (proportionate increase in all reported applications, including manure)
	Total of all applications of nitrogen (commercial fertilizer and manure applications) for cotton ≤60 pounds per bale	Increase rate to 90 pounds per bale (proportionate increase in all reported applications, including manure)
Phosphorus rate	Applied total of fertilizer and manure P over all crops in the crop rotation ≤ 1.1 times total harvest P removal over all crops in rotation.	Increase commercial P fertilizer application rates to reach 2.2 times harvest removal for the crop rotation (proportionate increase in all reported applications over the rotation), accounting also for manure P associated with increase to meet nitrogen applications for no practice scenario. Manure applications were NOT increased to meet the higher P rate for the no-practice scenario.
Commercial fertilizer application method	Incorporated or banded	Change to surface broadcast
Manure application method	Incorporated, banded, or injected	Change to surface broadcast
Commercial fertilizer application timing	Within 3 weeks prior to planting, at planting, or within 60 days after planting.	Moved to 3 weeks prior to planting. Manure applications were not adjusted for timing in the no-practice scenario.
Pesticides	1. Practicing high level of IPM 2. Practicing moderate level of IPM 3. Spot treatments 4. Partial field treatments	1. All incorporated applications changed to surface application. For each crop, the first application event after planting and 30 days prior to harvest replicated twice, 1 week and 2 weeks later than original. 2. Same as for high level of IPM, except replication of first application only 1 time, 1 week after original 3. Application rates for spot treatments were adjusted upward relative to the baseline rate to represent whole-field application (see text) 4. Application rates for partial field treatments were adjusted upward relative to the baseline rate to represent whole-field application (see text)

No-practice representation of conservation tillage

The no-practice tillage protocols are designed to remove the benefits of conservation tillage. For all crops grown with some kind of reduced tillage, including cover crops, the no-practice scenario simulates conventional tillage, based on the STIR (Soil Tillage Intensity Rating) value. Conventional tillage for the purpose of estimating conservation benefits is defined as any crop grown with a STIR value above 100. (To put this in context, no-till or direct seed systems have a STIR of less than 30, and that value is part of the technical standard for Residue Management, No-Till/Strip Till/Direct Seed [NRCS Practice Standard 329]). Those crops grown with a STIR value of less than 100 in the baseline conservation condition had tillage operations added in the no-practice scenario.

Simulating conventional tillage for crops with a STIR value of less than 100 requires the introduction of additional tillage operations in the field operations schedule. For the no-practice scenario, two consecutive tandem disk operations were added prior to planting. In addition to adding tillage, the hydrologic condition for assignment of the runoff curve number was changed from good to poor on all points receiving additional tillage. Points that are conventionally tilled for all crops in the baseline condition scenario are also modeled with a "poor" hydrologic condition curve number.

The most common type of tillage operation in the survey was disking, and the most common disk used was a tandem disk for nearly all crops, in all parts of the region, and for both dryland and irrigated agriculture. The tandem disk has a STIR value of 39 for a single use. Two consecutive disking operations will add 78 to the existing tillage intensity, which allows for more than 90 percent of the crops to exceed a STIR of 100 and yet maintain the unique suite and timing of operations for each crop in the rotation. Although a few sample points will have STIR values in the 80s or 90s after adding the two disking operations, the consistency of an across-the-board increase of 78 is simple and provides the effect of a distinctly more intense tillage system.

These additional two tillage operations were inserted in the simulation one week prior to planting, one of the least vulnerable times for tillage operations because it is close to the time when vegetation will begin to provide cover and protection.

No-practice representation of cover crops

The no-practice protocol for this practice removes the planting of the crop and all associated management practices such as tillage and fertilization. In a few cases the cover crops were grazed; when the cover crops were removed so were the grazing operations.

No-practice representation of irrigation practices

The no-practice irrigation protocols were designed to remove the benefits of better water management and the increased efficiencies of modern irrigation systems. Irrigation efficiencies are represented in APEX by a combination of three coefficients that recognize water losses from the water source to the field, evaporation losses with sprinkler systems, percolation losses below the root-zone during irrigation, and runoff at the lower end of the field. These coefficients are combined to form an over-all system efficiency that varies with soil type and land slope.

The quantity of water applied for all scenarios was simulated in APEX using an "auto-irrigation" procedure that applied irrigation water when the degree of plant stress exceeded a threshold. "Auto-irrigation" amounts were determined within pre-set single event minimums and maximums, and an annual maximum irrigation amount. APEX also used a pre-determined minimum number of days before another irrigation event regardless of plant stress.

In the no-practice representation, all conservation practices, such as Irrigation Water Management and Irrigation Land Leveling, were removed and samples with pressurized systems, such as center pivot, side roll, and low flow (drip), were changed to "hand move sprinklers," which represents an early form of pressure system. The "Big Gun" systems, which comprise 9.1 percent of the irrigated acres, are by and large already less efficient than the "hand move sprinklers," and most were not converted. However, 1.3 percent of the irrigated acres served by "Big Gun" systems are more efficient than the "hand move sprinklers," and these were converted in the no-practice representation. "Open discharge" gravity systems are used on approximately 5,300 acres or 2.5 percent of the irrigated area. The no-practice representation of gravity systems would use a ditch system with portals which is more efficient than the open discharge configuration, so these also were not converted.

For the no-practice scenario, the percentage of irrigated acreage with hand-move lines with impact sprinkler heads was increased to 89.7 percent (from 43.9 percent in the baseline conservation condition), 7.8 percent retained the Big Gun systems that were in use, and 2.5 percent were simulated with open discharge flood irrigation.

No-practice representation of nutrient management practices

The no-practice nutrient management protocols are designed to remove the benefits of proper nutrient management techniques.

The NRCS Nutrient Management standard (590) allows a variety of methods to reduce nutrient losses while supplying a sufficient amount of nutrient to meet realistic yield goals. The standard addresses nutrient loss in one of two primary ways: (1) by altering rates, form, timing, and methods of application, or (2) by installing buffers, filters, or erosion or runoff control practices to reduce mechanisms of loss. The latter method is covered by the structural practices protocols for the no-practice scenario. The goals of the nutrient management no-practice protocols are to alter three of the four basic aspects of nutrient application—rate, timing, and method. The form of application was not addressed because of the inability to determine if proper form was being applied.

Nitrogen rate. For the no-practice scenario, the amount of commercial nitrogen fertilizer applied was—

- increased to 1.98 times harvest removal for non-legume crops receiving less than or equal to 1.40 times the amount of nitrogen removed at harvest in the baseline scenario, except for cotton and small grain crops;
- increased to 2.0 times harvest removal for small grain crops receiving less than or equal to 1.60 times the amount of nitrogen removed at harvest in the baseline scenario, and
- increased to 90 pounds per bale for cotton crops receiving less than 60 pounds of nitrogen per bale in the baseline scenario.

The ratio of 1.98 for the increased nitrogen rate was determined by the average rate-to-yield-removal ratio for crops exceeding the application-removal ratio of 1.4. Where nitrogen was applied in multiple applications, each application was increased proportionately. For sites receiving manure, the threshold for identifying good management was the total nitrogen application rate, both manure and fertilizer, and both fertilizer and manure were increased proportionately to reach the no-practice scenario rate. The assessment for using appropriate nitrogen application rates was made on an average annual basis for each crop in the rotation using average annual model output on nitrogen removed with the yield at harvest in the baseline conservation condition scenario.

Phosphorus rate. The threshold for identifying proper phosphorus application rates was 1.1 times the amount of phosphorus taken up by all the crops in rotation and removed at harvest. The lower threshold for phosphorus was used because phosphorus is not lost through volatilization to the atmosphere and much less is lost through other pathways owing to strong bonding of phosphorus to soil particles. For the no-practice scenario, the amount of commercial phosphorus fertilizer applied was increased to 2.2 times the harvest removal rate. For crops receiving manure, any increase in phosphorus from manure added to meet the nitrogen criteria for no-practice was taken into account in setting the no-practice application rate. However, no adjustment was made to manure applied at rates below the P threshold because the appropriate manure rate was based on the nitrogen level in the manure. The ratio of 2.2 for the increased phosphorus rate was determined by the average rate-to-yield-removal ratio for crops with phosphorus applications exceeding 1.1 times the amount of phosphorus taken up by all the crops in rotation and removed at harvest. Multiple commercial phosphorus fertilizer applications were increased proportionately to meet the 2.2 threshold.

Timing of application. Nutrients applied closest to the time when a plant needs them are the most efficiently utilized and least likely to be lost to the surrounding environment. All commercial fertilizer applications occurring within 3 weeks prior to planting, at planting, or within 60 days after planting were moved back to 3 weeks prior to planting for the no-practice scenario. For example, split applications that occur within 60 days after planting are moved to a single application 3 weeks before planting. Timing of manure applications was not adjusted in the no-practice scenario.

Method of application. Nutrient applications, including manure applications, that were incorporated or banded were changed to a surface broadcast application method.

No-practice representation of pesticide management practices

Pesticide management for conservation purposes is a combination of three types of interrelated management activities:

1. A mix of soil erosion control practices that retain pesticide residues within the field boundaries.
2. Pesticide use and application practices that minimize the risk that pesticide residues pose to the surrounding environment.
3. Practice of Integrated Pest Management (IPM), including partial field applications and spot treatment.

The first activity is covered by the no-practice representation of structural practices and residue and tillage management. The second activity, for the most part, cannot be simulated in large-scale regional modeling because of the difficulty in assuring that any changes in the types of pesticides applied or in the method or timing of application would provide sufficient protection against pests to maintain crop yields.[13] Farmers, of course, have such options, and environmentally conscientious farmers make tradeoffs to reduce environmental risk. But without better information on the nature of the pest problem both at the field level and in the surrounding area, modelers have to resort to prescriptive and generalized approaches to simulate alternative pesticides and application techniques, which would inevitably be inappropriate for many, if not most, of the acres simulated.

The no-practice representation for pesticide management is therefore based on the third type of activity—practicing IPM.

One of the choices for methods of pesticide application on the survey was “spot treatment.” Typically, spot treatments apply to a small area within a field and are often treated using a hand-held sprayer. Spot treatment is an IPM practice, as it requires scouting to determine what part of the field to treat and avoids treatment of parts of the field that do not have the pest problem. The reported rate of application for spot treatments was the rate per acre treated. For the baseline simulation, it was assumed that all spot treatments covered 5 percent of the field. Since the APEX model run and associated acreage weight for the sample point represented the whole field, the application rate was adjusted downward to 5 percent of the per-acre rate reported for the baseline scenario. For the no-practice scenario, the rate as originally reported was used, simulating treatment of the entire field rather than 5 percent of the field. In the Chesapeake Bay region, there were no sample points with spot treatments.

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[13] The APEX model can simulate pesticide applications, but it does not currently include a pest population model that would allow simulation of the effectiveness of pest management practices. Thus, the relative effectiveness of pesticide substitution or changes in other pest management practices cannot be evaluated.

Partial field treatments were simulated in a manner similar to spot treatments. For the baseline scenario, application rates were reduced proportionately according to how much of the field was treated. For the no-practice scenario, the rate as reported in the survey was used, simulating treatment of the entire field. However, this adjustment for the no-practice scenario was only done for partial field treatments less than one-third of the field, as larger partial field treatments could have been for reasons unrelated to IPM. In the Chesapeake Bay region, there were no sample points with partial field treatments.

The IPM indicator, described in the previous chapter, was used to adjust pesticide application methods and to increase the frequency of applications to represent “no IPM practice.” For samples classified as having either high or moderate IPM use, all soil-incorporated pesticide applications in the baseline condition were changed to surface applications in the no-practice scenario. For high IPM cases, the first application event between planting and 30 days before harvest was replicated twice for each crop, one week and two weeks after its original application. For moderate IPM cases, the first application event was replicated one time for each crop, one week after its original application.

No-practice representation of land in long-term conserving cover

The no-practice representation of land in long-term conserving cover is cultivated cropping with no conservation practices in use. For each CRP sample point, a set of cropping simulations was developed to represent the probable mix of management that would be applied to the point if it were cropped. Cropped sample points were matched to each CRP sample point on the basis of slope, soil texture, soil hydrologic group, and geographic proximity. The cropped sample points that matched most closely were used to represent the cropped condition that would be expected at each CRP sample point if the field had not been enrolled in CRP. In most cases, seven “donor” points were used to represent the crops that were grown and the various management activities to represent crops and management for the CRP sample point “as if” the acres had not been enrolled in CRP. The crops and management activities of each donor crop sample were combined with the site and soil characteristics of the CRP point for the no-practice representation of land in long-term conserving cover.

Effects of Practices on Fate and Transport of Water

Water is a potent force that interacts with or drives almost all environmental processes acting within an agricultural production system. The hydrologic conditions prevalent in the Chesapeake Bay region are critical to understanding the estimates of sediment, nutrient, and pesticide loss presented in subsequent sections. The APEX model simulates hydrologic processes at the field scale—precipitation, irrigation, evapotranspiration, surface water runoff, infiltration, and percolation beyond the bottom of the soil profile.

Baseline condition for cropped acres

Precipitation and irrigation are the sources of water for a field. Annual precipitation over the 47-year simulation averaged about 42 inches in this region (table 12). (Also see figs. 5 and 6.) Only about 5 percent of cropped acres are irrigated, at an average application of 12 inches per year.

Most of the water that leaves the field is lost through evaporation and transpiration (evapotranspiration) (fig. 13). Evapotranspiration is the dominant loss pathway for 98 percent of cropped acres. On average, about 64 percent of the water loss for cropped acres in this region is through evapotranspiration (table 12). Model results indicate that evapotranspiration losses vary, however, according to soil characteristics and land cover; evapotranspiration ranges from about 40 percent to 80 percent of the total amount of water that leaves the field (fig. 14).

Loss of water through subsurface flow pathways is the second largest source of water loss at an average of about 11 inches per year for cropped acres (table 12). Subsurface flow pathways include: (1) deep percolation to groundwater, including groundwater return flow to surface water, (2) subsurface flow into a tile or ditch drainage system, (3) lateral subsurface outflow, and (4) quick-return subsurface flow. The percentage of water loss represented by subsurface flows averages about 25 percent for cropped acres (table 12). However, this percentage varies from less than 10 percent to over 50 percent for cropped acres in the Chesapeake Bay region, as shown in figure 14.

Surface water runoff averages about 12 percent of water loss for cropped acres (table 12), ranging from less than 5 percent to 20 percent (fig. 14). Average surface water loss for cropped acres is about 5 inches per year (table 12). The amount of surface water runoff varies from acre to acre, ranging from an annual average of about 2 inches per year for some acres to over 10 inches per year.

Effects of conservation practices on cropped acres

Structural water erosion control practices, residue management practices, and reduced tillage slow the flow of surface water runoff and allow more of the water to infiltrate into the soil. Model simulations indicate that conservation practices have reduced surface water runoff by about 0.7 inch per year averaged over all acres, representing a 12-percent reduction for the region (table 12).

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Figure 13. Estimates of average annual water lost through three loss pathways for cropped acres in the Chesapeake Bay region

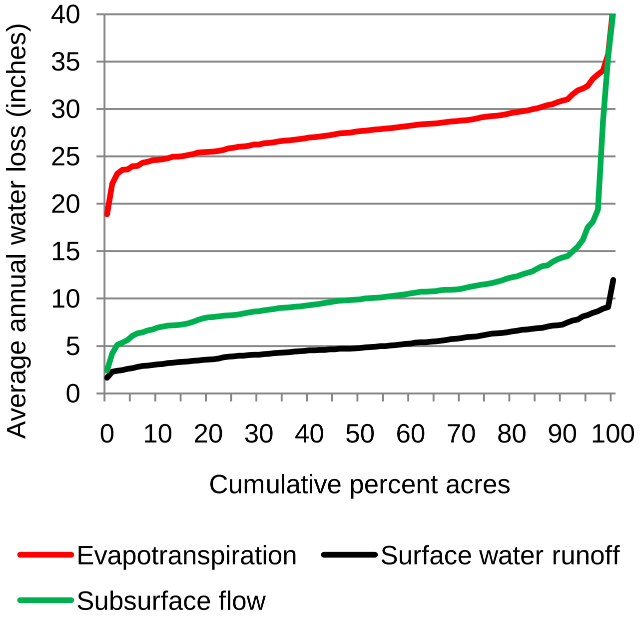
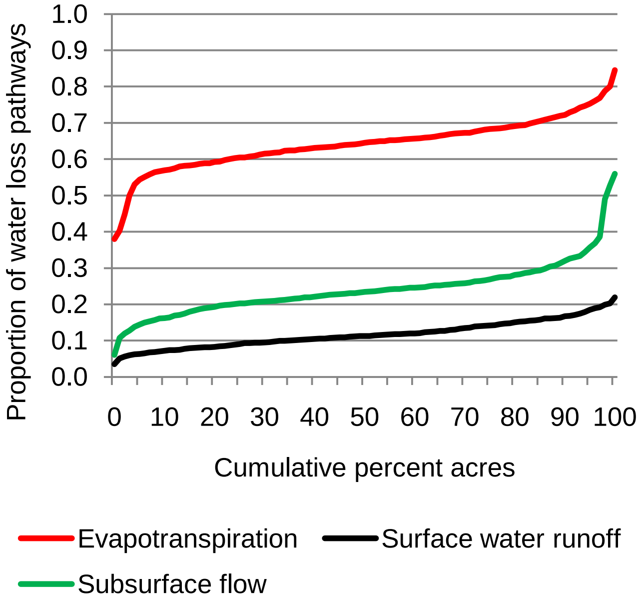


Figure 14. Cumulative distributions of the proportion of water lost through three loss pathways for cropped acres, Chesapeake Bay region



Note: The horizontal axis consists of percentiles for each pathway; a given percentile for one curve will not represent the same acres on another curve.

The re-routing of surface water to subsurface flows is shown graphically in figures 15 and 16 for cropped acres The no-practice scenario curve in figure 15 shows what the distribution of surface water runoff would be if there were no conservation practices in use—more surface water runoff and thus less subsurface flow.

Table 12. Field-level effects of conservation practices on water loss pathways for cultivated cropland in the Chesapeake Bay region

Model simulated outcome	Baseline conservation condition	No-practice scenario	Reduction due to practices	Percent reduction
Cropped acres (4.3 million acres)				
Water sources				
Non-irrigated acres				
Average annual precipitation (inches)	42.2	42.2	0.0	0
Irrigated acres				
Average annual precipitation (inches)	42.8	42.8	0.0	0
Average annual irrigation water applied (inches)*	12.3	22.7	10.4	46
Water loss pathways				
Average annual evapotranspiration (inches)	27.7	28.0	0.2	1
Average annual surface water runoff (inches)	5.1	5.7	0.7	12
Average annual subsurface water flows (inches)**	10.7	9.9	-0.8***	-8***
Land in long-term conserving cover (0.1 million acres)				
Water sources*				
Average annual precipitation (inches)	41.9	41.9	0.0	0
Average annual irrigation water applied (inches)*	0.0	0.1	0.1	100
Water loss pathways				
Average annual evapotranspiration (inches)	25.1	26.7	1.7	6
Average annual surface water runoff (inches)	4.3	5.9	1.6	27
Average annual subsurface water flow (inches)**	12.7	9.5	-3.2***	-33***

* About 5 percent of the cropped acres in the Chesapeake Bay region are irrigated. Land in long-term conserving cover was not irrigated, but some farming practices used to simulate a cropped condition to represent the no-practice scenario included irrigation. Values shown in the table for land in long-term conserving cover are averages over all acres, including non-irrigated acres.

** Subsurface flow pathways include: (1) deep percolation to groundwater, including groundwater return flow; (2) subsurface flow into a drainage system; (3) lateral subsurface outflow; and (4) quick-return subsurface flow.

*** Represents an average gain in subsurface flows of 0.8 inch per year (8 percent increase) for cropped acres due to the use of conservation practices; represents an average gain of 3.2 inches in subsurface flow for land in long-term conserving cover.

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text.

Note: Model simulation results for the baseline conservation condition are presented in appendix B for the four subregions.

Figure 15. Estimates of average annual surface water runoff for cropped acres in the Chesapeake Bay region

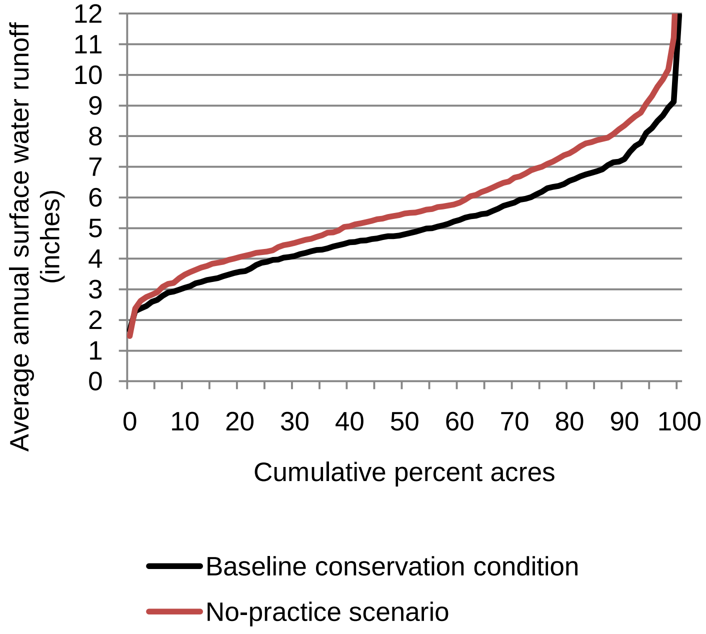
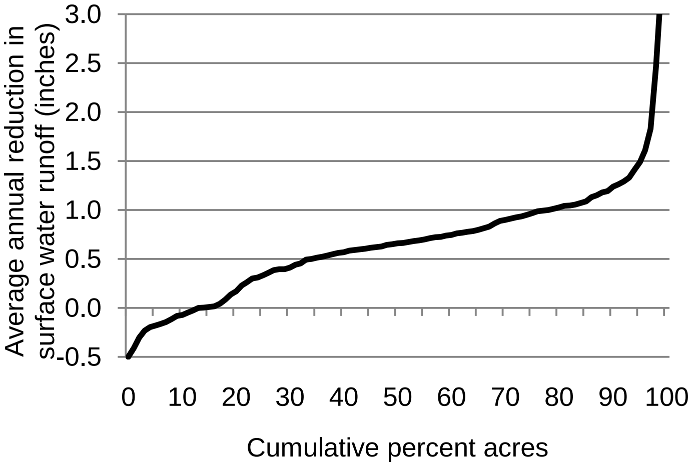


Figure 16. Estimates of average annual reduction in surface water runoff due to the use of conservation practices on cropped acres in the Chesapeake Bay region



Note: About 12 percent of the acres had less surface water runoff in the no-practice scenario than the baseline conservation condition. In general, these gains in surface water runoff due to practices occur on soils with low to moderate potential for surface water runoff together with: (1) higher nutrient application rates in the no-practice scenario that result in more biomass production, which can reduce surface water runoff (typically rotations with hay or continuous corn); or (2) the additional tillage simulated in the no-practice scenario provided increased random roughness of the surface reducing runoff on nearly level landscapes with low crop residue rotations.

Reductions in surface water runoff due to conservation practices range to over 3 inches per year (fig. 16).The variability in reductions due to practices reflects different levels of conservation treatment as well as differences in precipitation and inherent differences among acres for water to run off.

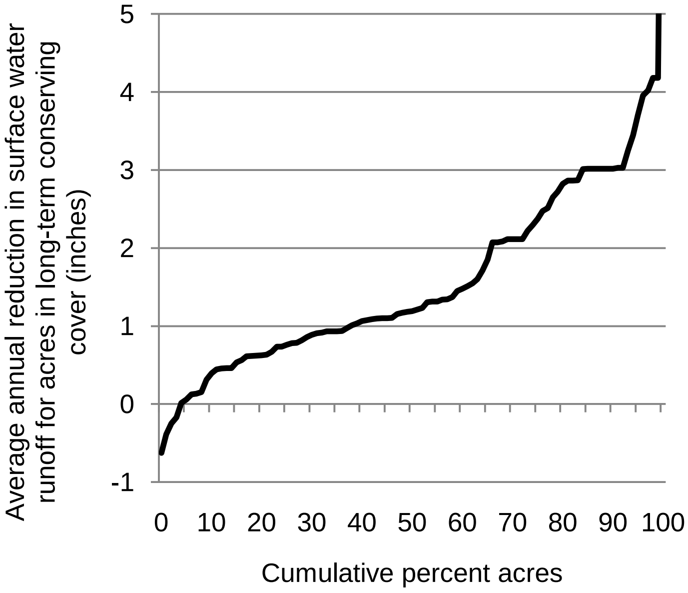
Use of improved irrigation systems in the Chesapeake Bay region increases overall system efficiency from 42 percent in the no-practice scenario to 68 percent in the baseline scenario. This change in efficiency represents an annual decreased need of water diversions of about 10 inches where irrigation is used (table 12).

Land in long-term conserving cover

Model simulations further show that land in long-term conserving cover (baseline conservation condition) in the region also has, on average, less surface water runoff and more subsurface flow than would occur if the land was cropped (table 12). Evapotranspiration is slightly lower for land in long-term conserving cover, as well.

Reductions in surface water runoff due to conversion to long-term conserving cover average 1.6 inches per year in this region (table 12), but range to above 4 inches per year for some acres (fig. 17).

Figure 17. Estimates of average annual reduction in surface water runoff due to conversion to long-term conserving cover in the Chesapeake Bay region



Cumulative Distributions Show How Effects of Conservation Practices Vary Throughout the Region

The design of this study provides the opportunity to examine not only the overall mean value for a given outcome, but also the entire distribution of outcomes. This is possible because outcomes are estimated for each of the 771 sample points used to represent cropped acres in the Chesapeake Bay region and for each of the 61 sample points used to represent land in long-term conserving cover. Cumulative distributions show the full set of estimates and thus demonstrate how conditions and the effects of conservation practices vary throughout the region.

Cumulative distributions shown in this report are plots of the value for each percentile. In figure 15, for example, the curve for average annual surface water runoff for the baseline conservation condition consists of each of the percentiles of the distribution of 771 surface water runoff estimates, weighted by the acres associated with each sample point. The 10th percentile for the baseline conservation condition is 3.1 inches per year, indicating that 10 percent of the acres have 3.1 inches or less of surface water runoff, on average. Similarly, the same curve shows that 25 percent of the acres have surface water runoff less than 3.9 inches per year. The 50th percentile—the median—is 4.8 inches per year, which in this case is close to the mean value of 5.1 inches per year. At the high end of the distribution, 90 percent of the acres in this region have surface water runoff less than 7.3 inches per year; and conversely, 10 percent of the acres have surface water runoff greater than 7.3 inches per year.

Thus, the distributions show the full range of outcomes for cultivated cropland acres in the Chesapeake Bay region. The full range of outcomes for the baseline condition is compared to that for the no-practice scenario in figure 15 to illustrate the extent to which conservation practices reduce surface water runoff throughout the region.

Figure 16 shows the effects of conservation practices on surface water runoff using the distribution of the *reduction* in surface water runoff, calculated as the outcome for the no-practice scenario minus the outcome for the baseline conservation condition at each of the 771 cropped sample points. This distribution shows that, while the mean reduction is 0.7 inch per year, 5 percent of the acres have reductions due to conservation practices greater than 1.5 inches per year and 12 percent of the acres actually have small increases in surface water runoff (i.e., negative reductions) as a result of soil erosion control conservation practice use. (See footnote to figure 16 for an explanation of the conditions that result in gains in surface water runoff due to conservation practices.)

Effects of Practices on Wind Erosion

Wind erosion removes the most fertile parts of the soil such as the lighter, less dense soil constituents including organic matter, clays, and silts. Wind erosion occurs when the soil is unprotected and wind velocity exceeds about 13 miles per hour near the surface. Wind velocity, tillage, vegetative cover, and the texture and structure of the soil are primary determinants of wind erosion. Wind erosion is estimated in APEX using the Wind Erosion Continuous Simulation (WECS) model. The estimated wind erosion rate is the amount of eroded material leaving the downwind edge of the field.

Wind erosion is a relatively minor resource concern in the Chesapeake Bay region. The greatest concern with wind erosion in the Chesapeake Bay region is crop damage to young seedlings exposed to windblown material. Wind erosion rates as low as 0.5 ton per acre are known to cause physical damage to young seedlings.

For all cropped acres, model simulations show that the average annual rate of wind erosion is only 0.03 ton per acre (table 13). Model simulations further show, however, that wind erosion can be an issue in some years for some acres (fig. 18). In the most extreme year included in the model simulations (representing 1997), annual wind erosion exceeded 0.5 ton per acre for 6 percent of the cropped acres.

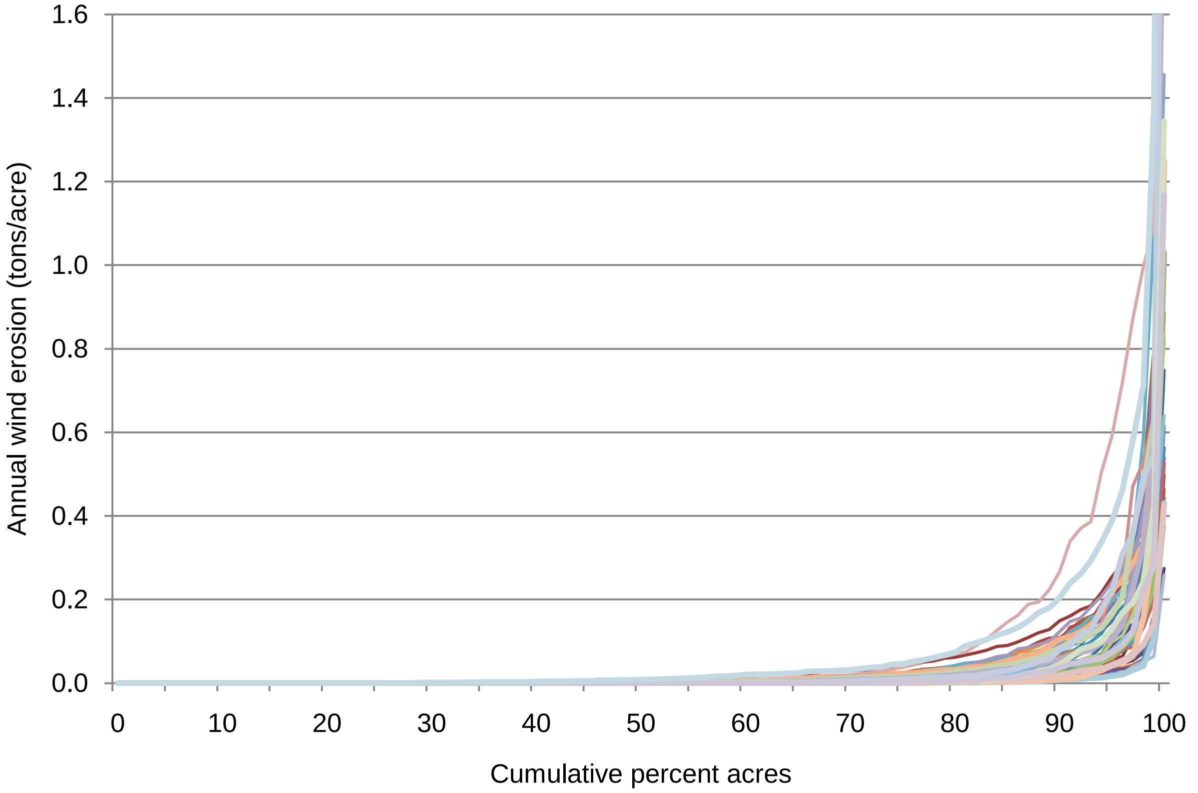
Table 13. Average annual wind erosion (tons/acre) for cultivated cropland in the Chesapeake Bay region

	Baseline conservation condition	No-practice scenario	Reduction due to practices	Percent reduction
Cropped acres	0.027	0.056	0.029	52
Land in long-term conserving cover	<0.001	0.008	0.008	100

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Model simulation results for the baseline conservation condition are presented in appendix B for the 4 subregions.

Structural practices for wind erosion control are in use on only 7 percent of the cropped acres in the Chesapeake Bay region. However, other practices common in the region, such as residue and tillage management, reduced tillage, and various water erosion control practices, are also effective in reducing wind erosion. Model simulations indicate that conservation practices have reduced the average wind erosion rate by 52 percent in the region (table 13). Even though wind erosion is not a major resource concern in the Chesapeake Bay region, these reductions in wind erosion rates are still significant.

Figure 18. Distribution of annual wind erosion rate for each year of the 47-year model simulation, Chesapeake Bay region



Note: This figure shows how annual wind erosion (tons per acre per year) varies within the region and from year to year in the model simulation for cropped acres. Each of the 47 curves shown above represents a single year of data and shows how annual wind erosion varies over the region in that year, starting with the acres with the lowest rates and increasing to the acres with the highest rates. The family of curves shows how annual wind erosion rates vary from year to year.

Effects of Practices on Water Erosion and Sediment Loss

Sheet and rill erosion is the detachment and movement of soil particles within the field that occurs during rainfall events. Controlling sheet and rill erosion is important for sustaining soil productivity and preventing soil from leaving the field.

Sediment loss is the sediment that is transported beyond the edge of the field by water, where the field includes any edge-of-field filtering and buffering conservation practices. Soil erosion and sedimentation are separate but interrelated resource concerns. Soil erosion is the detachment and transport of soil particles, while sedimentation is that portion of the eroded material that settles out in areas onsite or offsite. Sediment loss, as estimated in this study, includes the portion of the sheet and rill eroded material that settles offsite as well as some sediment that originates from gully erosion processes.[14] Sediment is composed of detached and transported soil minerals, organic matter, plant and animal residues, and associated chemical and biological compounds.

The Chesapeake Bay region has one of the highest proportions of cropland classified as highly erodible for water erosion of all the basins studied (44 percent). Most of these soils occur in the Piedmont, Appalachian, or Allegheny mountain or plateau physiographic regions. Soils in this region tend to occur on moderately sloping to steep landscapes. They are often relatively shallow agricultural soils with approximately half of the HEL lands classified with a soil loss tolerance (T) of 3 tons/acre/year.

Sheet and rill erosion

Model simulations show that sheet and rill erosion in the Chesapeake Bay region averages about 1.0 ton per acre per year (table 14). Sheet and rill erosion rates are higher for highly erodible land, averaging 1.6 tons per acre per year compared to the average annual rate for non-highly erodible land of 0.5 ton per acre.

Model simulation results also show that conservation practices have reduced sheet and rill erosion on cropped acres in the Chesapeake Bay region by an average of 0.78 ton per acre per year, representing a 44-percent reduction on average (table 14). While the average annual reduction in sheet and rill erosion for highly erodible land is more than three times that for non-highly erodible acres (table 14), the percent reduction due to conservation practices is about the same.

For land in long-term conserving cover, sheet and rill erosion has been reduced from 2.48 tons per acre per year if cropped without conservation practices to 0.02 ton per acre (table 14), on average.

Sediment loss due to water erosion

Baseline condition for cropped acres. The average annual sediment loss for cropped acres in the Chesapeake Bay region is 1.2 tons per acre per year, according to the model simulation (table 14). As seen for sheet and rill erosion, sediment loss for highly erodible land is much higher than for non-highly erodible land, even though a higher proportion of highly erodible acres have structural water erosion control practices in use.

On an annual basis, sediment loss can vary considerably. Figure 19 shows that, with the conservation practices currently in use in the Chesapeake Bay region, annual sediment loss is below 2 tons per acre for about 60 percent of the acres under all conditions, including years with high precipitation. In contrast, sediment loss exceeds 12 tons per acre in one or more years on about 10 percent of the cropped acres.

Figure 19 also illustrates the extent to which high sediment losses are restricted to a minority of acres within the region, even during years with high precipitation. These are the acres that have the highest inherent vulnerability to water erosion and have inadequate soil erosion control.

Effects of conservation practices on cropped acres. Model simulations indicate that the use of conservation practices in the Chesapeake Bay region has reduced average annual sediment loss due to water erosion by 55 percent for cropped acres in the region, including both treated and untreated acres (table 14). Without conservation practices, the average annual sediment loss for these acres would have been 2.64 tons per acre per year compared to 1.18 tons per acre average for the baseline conservation condition. Figure 20 shows that about 61 percent of the acres would have less than 2 tons per acre per year sediment loss without practices, on average, compared to 83 percent with conservation practices.

Reductions in sediment loss due to conservation practices are much higher for some acres than others, reflecting both the level of treatment and the inherent erodibility of the soil. For about 60 percent of cropped acres, the average annual sediment loss reduction due to practices is less than 1 ton per acre (fig. 21). The top 10 percent of the acres had reductions in average annual sediment loss greater than 3.8 tons/acre.

Acres with a combination of structural practices and residue and tillage management have the highest percent reduction in sediment loss (table 15). Acres that are treated with structural practices, meet tillage intensity criteria for no-till or mulch till, and are gaining soil organic carbon (about 19 percent of cropped acres) have reduced sediment loss by 80 percent, on average. For these treated acres, annual sediment loss averages only about 0.5 ton per acre.

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[14] For this study, the APEX model was set up to estimate sediment loss using a modified version of USLE, called MUSS, which uses an internal sediment delivery ratio to estimate the amount of eroded soil that actually leaves the boundaries of the field. A large percentage of the eroded material is redistributed and deposited within the field or trapped by buffers and other conservation practices and does not leave the boundary of the field, which is taken into account in the sediment delivery calculation. The estimate also includes some gully erosion and some ephemeral gully erosion. For this reason, sediment loss rates can exceed sheet and rill erosion rates.

Table 14. Field-level effects of conservation practices on erosion and sediment loss for cultivated cropland in the Chesapeake Bay region

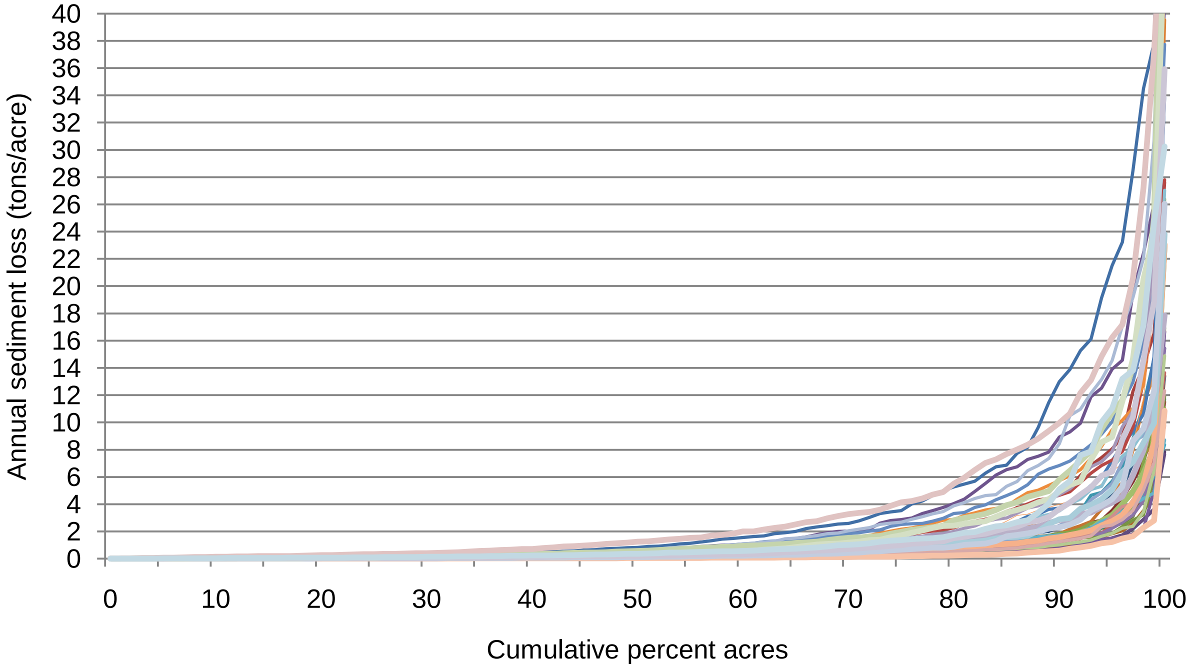
Model simulated outcome	Baseline conservation condition	No-practice scenario	Reduction due to practices	Percent reduction
Cropped acres (4.3 million acres)				
Average annual sheet and rill erosion (tons/acre)*	0.99	1.77	0.78	44
Average annual sediment loss at edge of field due to water erosion (tons/acre)	1.18	2.64	1.46	55
Highly erodible land (44 percent of cropped acres)				
Average annual sheet and rill erosion (tons/acre)*	1.62	2.87	1.25	44
Average annual sediment loss at edge of field due to water erosion (tons/acre)	2.07	4.63	2.56	55
Non-highly erodible land (56 percent of cropped acres)				
Average annual sheet and rill erosion (tons/acre)*	0.50	0.92	0.41	45
Average annual sediment loss at edge of field due to water erosion (tons/acre)	0.49	1.08	0.59	55
Land in long-term conserving cover (0.1 million acres)				
Average annual sheet and rill erosion (tons/acre)*	0.02	2.48	2.46	99
Average annual sediment loss at edge of field due to water erosion (tons/acre)	0.02	4.26	4.24	100

* Estimated using the Revised Universal Soil Loss Equation.

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text.

Note: Model simulation results for the baseline conservation condition are presented in appendix B for the 4 subregions.

Figure 19. Distribution of annual sediment loss for each year of the 47-year model simulation, Chesapeake Bay region



Note: This figure shows how annual sediment loss (tons per acre per year) varies within the region and from year to year in the model simulation for cropped acres. Each of the 47 curves shown above represents a single year of data and shows how annual sediment loss varies over the region in that year, starting with the acres with the lowest sediment loss and increasing to the acres with the highest sediment loss. The family of curves shows how annual sediment loss varies from year to year.

Figure 20. Estimates of average annual sediment loss for cropped acres in the Chesapeake Bay region

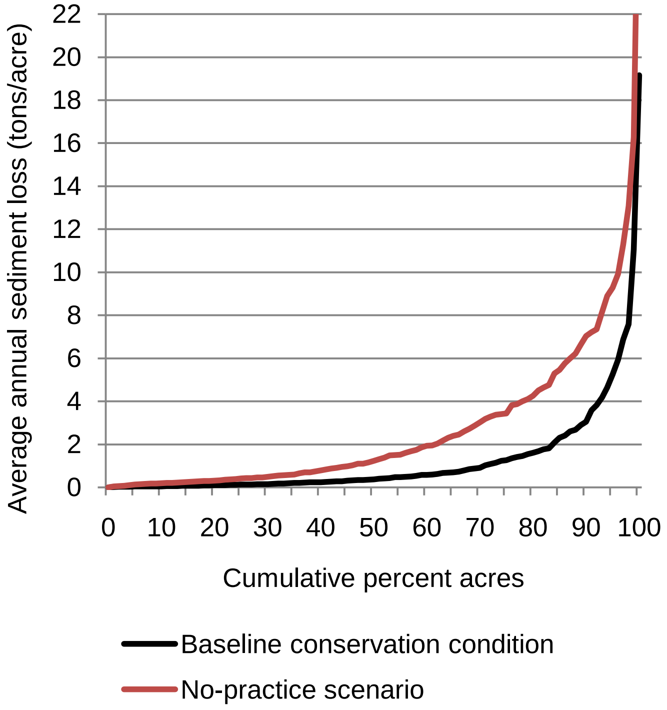
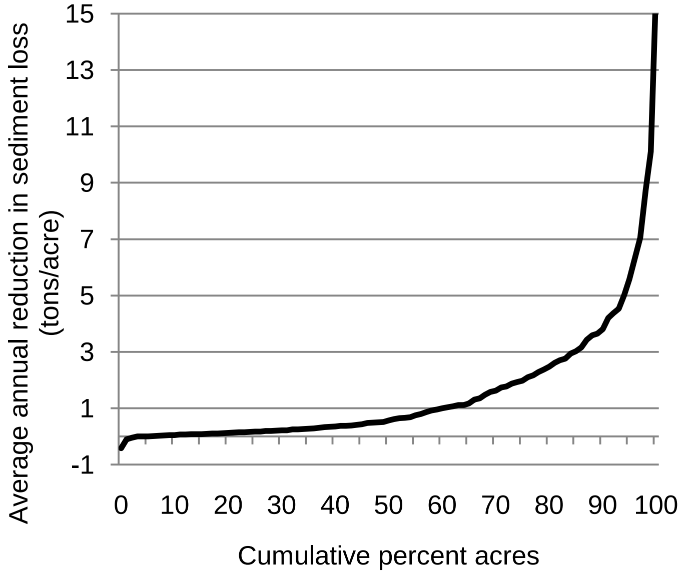


Figure 21 Estimates of average annual reduction in sediment loss due to the use of conservation practices on cropped acres in the Chesapeake Bay region



Note: About 2 percent of the acres had less sediment loss in the no-practice scenario than the baseline conservation condition, resulting from the increase is surface water runoff on some acres due to conservation practices. See footnote to figure 16.

Table 15. Estimates of effects of combinations of structural practices and residue and tillage management on average annual sediment loss for cropped acres in the Chesapeake Bay region

		Average annual sediment loss (tons/acre)			
Conservation treatment	**Percent of cropped acres**	**Baseline conservation condition**	**No-practice scenario**	**Reduction due to practices**	**Percent reduction**
No-till or mulch till with carbon gain, no structural practices	21	0.34	0.81	0.46	57
No-till or mulch till with carbon loss, no structural practices	26	1.30	2.00	0.70	35
Some crops with reduced tillage, no structural practices	2	1.25	1.68	0.43	26
Structural practices and no-till or mulch till with carbon gain	19	0.50	2.55	2.05	80
Structural practices and no-till or mulch till with carbon loss	21	2.19	5.24	3.05	58
Structural practices and some crops with reduced tillage	3	0.69	2.80	2.11	75
Structural practices only	3	2.16	4.06	1.90	47
No water erosion control treatment	4	2.22	2.29	0.08	3*
All acres	100	1.18	2.64	1.46	55

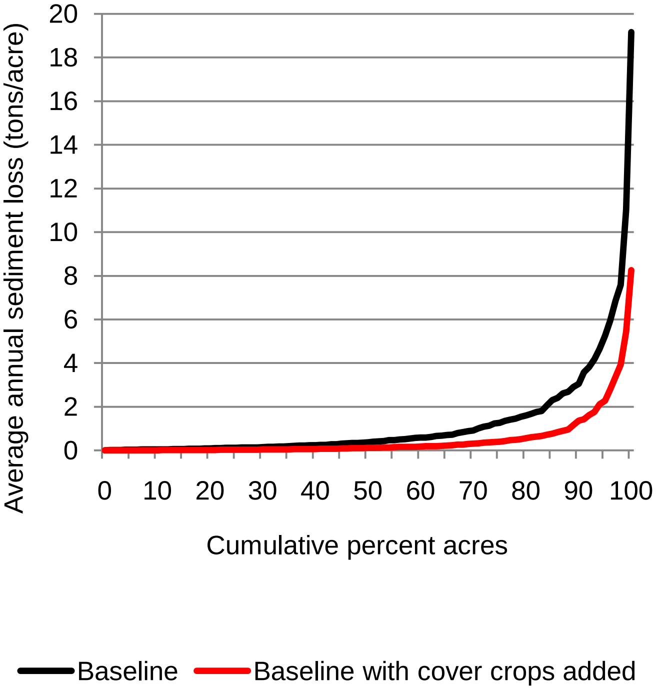
* For non-irrrigated sample points, the reduction due to practices for these acres with no water erosion control treatment was close to zero, as expected. For irrigated sample points, additional irrigation water was added to simulate lower water use efficiencies in the no-practice scenario, which contributes to higher sediment loss in the no-practice scenario. In addition, sediment loss was slightly affected by the higher nutrient application rates simulated in the no-practice scenario to estimate the benefits of nutrient management practices where they occurred.

Note: Differences in slope, soil texture, hydrologic group, and precipitation for acres in different treatment groups account for some of the differences shown in this table. Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Percents may not add to totals because of rounding.

Effects of cover crops on sediment loss. A "what if" scenario that simulated the use of cover crops on all cropped acres was conducted to demonstrate the potential for cover crops to reduce sediment and nutrient loss from fields in this region (see Appendix C). Results showed that full adoption of cover crops in this region would further reduce sediment loss by an average of 59 percent, compared to the 2003–06 baseline condition, bringing the average annual sediment loss for the region to less than 0.5 ton per acre per year.

However, as shown in figures 22 and 23, the effects of cover crops on reducing sediment loss is modest for the majority of cropped acres—generally those with the lowest losses in the 2003–06 baseline condition. The median sediment loss reduction would be only about 0.2 ton per acre per year. About 60 percent of the acres would have a reduction in sediment loss of 0.35 tons per acre or less (fig. 23). In contrast, 18 percent of the acres would have average annual reductions of 1 ton per acre or more. Nonetheless, figure 22 shows that full adoption of cover crops would bring average annual sediment loss to below 2 tons per acre for 93 percent of the acres in the region, compared to 83 percent for the 2003–06 baseline condition.

Figure 22. Estimates of average annual sediment loss for cropped acres, comparing the baseline scenario to a "what if" scenario with cover crops added to all cropped acres, Chesapeake Bay region



Land in long-term conserving cover. Acres in long-term conserving cover have very little erosion or sediment loss, and thus show nearly 100 percent reductions when compared to a cropped condition (table 14). If these 100,000 acres were still being cropped without any conservation practices, sediment loss would average about 4.3 tons per acre per year.

Reductions in sediment loss for land in long-term conserving cover compared to the same acres with crops and no conservation practices vary considerably, as shown in figure 24. While the average reduction over all acres in long-term conserving cover is 4.2 tons per acre per year, 40 percent of the acres in long-term conserving cover have reductions of less than 2 tons per acre per year. Reductions greater than 10 tons per acre per year occur on about 11 percent of the acres with long-term conserving cover.

Figure 23. Estimates of the average annual potential reduction in sediment loss if cover crops were used on all cropped acres in the Chesapeake Bay region

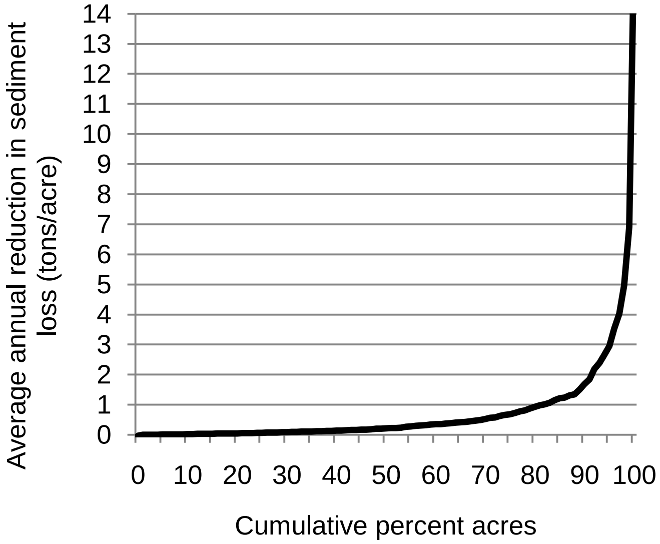
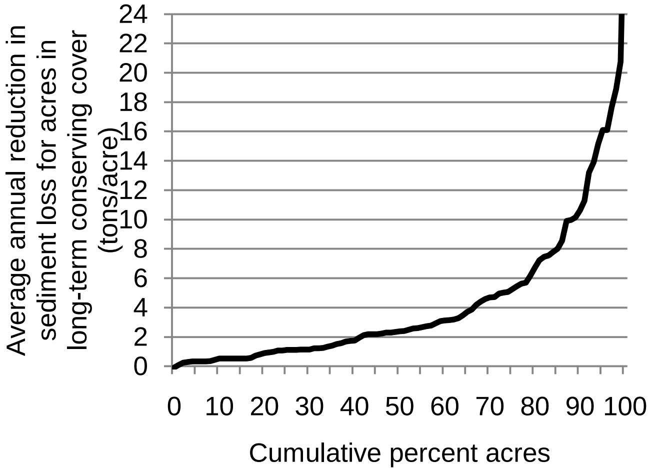


Figure 24. Estimates of average annual reduction in sediment loss due to conversion to long-term conserving cover in the Chesapeake Bay region



Effects of Practices on Soil Organic Carbon

The landscape and climate in the Chesapeake Bay region is much less conducive to maintaining and enhancing soil organic carbon relative to landscapes and climate of the soils in the Midwest. The combination of higher rainfall on more sloping soils and milder winters that allow for more degradation of organic materials make carbon accumulation far more challenging. The soils in this region developed residuum from igneous and metamorphic bedrock, glacial outwash or sandy coastal plain sediments. These materials are highly weathered with mixed or siliceous mineralogy, causing them to be inherently less fertile. The highly weathered, less reactive nature of these soils makes them less able to withstand even moderately intense tillage and maintain or enhance carbon stores relative to regions of the country like the Mississippi River drainage basin.

In this study, estimation of soil organic carbon change is based on beginning soil characteristics that reflect the effects of years of traditional conventional tillage practices and older, lower yielding crop varieties. These effects generally resulted in soils with organic carbon levels at or near their low steady state. Modern high yielding crop varieties with and without the adoption of conservation tillage tend to readily improve the status of carbon in many soils, especially those with beginning stocks far less than the steady state representation of the present management. Beginning the simulations at a lower steady state for carbon allows for a more equitable comparison of conservation practices, particularly conservation tillage. Because of this, however, model estimates of soil organic carbon change may be somewhat larger than shown in other studies. Nevertheless, model estimates obtained in this study fall within the expected range for the continuum of adoption of new crop genetics and tillage practices.

Baseline condition for cropped acres

Model simulation shows that for the baseline conservation condition the average annual soil organic carbon change is a loss of about 27 pounds per acre per year, on average (table 16), with about 43 percent of cropped acres gaining annually in soil organic carbon and 57 percent losing soil organic carbon, on average. These estimates account for losses of carbon with sediment removed from the field by wind and water erosion. Loss of soil organic carbon due to wind and water erosion averages about 152 pounds per acre per year for the baseline conservation condition (table 16).

Cropped acres that are gaining soil organic carbon every year provide soil quality benefits that enhance production and reduce the potential for sediment, nutrient, and pesticide losses. Soil organic carbon improves the soil's ability to function with respect to nutrient cycling, improves water holding capacity, and reduces erodibility. However, enhancement of carbon stores on a scale seen in the Midwestern basins could only occur in this region with significant shifts in crop mixes toward rotations with hay or pasture as components.

Given the challenging nature of the inherent conditions of this region, maintenance of soil organic carbon is also an important benchmark. Cropping systems can be considered to be maintaining soil organic carbon if average annual losses do not exceed 100 pounds per acre per year; this rate of change is typically too small to detect via typical soil sampling over a 20-year period. Applying this criterion, about 33 percent of the acres in the region would be considered to be maintaining (but not enhancing) soil organic carbon. When combined with acres enhancing soil organic carbon, a total of 76 percent of the acres in the region would be either maintaining or enhancing soil organic carbon. This achievement is in large part due to the high rate of conservation tillage adoption, particularly no-till and the high residue crop rotations on most of the acres.

Effects of conservation practices on cropped acres

Without conservation practices, the annual change in soil organic carbon would be an average loss of 68 pounds per acre per year, compared to an average loss of 27 pounds per acre for the baseline (table 16). Thus, conservation practices in the region have resulted in an average annual gain in soil organic carbon of 41 pounds per acre per year on cropped acres.

Table 16. Field-level effects of conservation practices on soil organic carbon for cultivated cropland in the Chesapeake Bay region

Model simulated outcome	Baseline conservation condition	No-practice scenario	Reduction due to practices	Percent reduction
Cropped acres (4.3 million acres)				
Average annual loss of carbon with wind and water erosion (pounds/acre)	152	180	28	15
Average annual change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)	-27	-68	41*	--
Land in long-term conserving cover (0.1 million acres)				
Average annual loss of carbon with wind and water erosion (pounds/acre)	75	256	281	71
Average annual change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)	233	-100	333*	--

***** Gain in soil organic carbon due to conservation practices.
Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text.
Note: Model simulation results for the baseline conservation condition are presented in appendix B for the 4 subregions.

However, average annual change in soil organic carbon varies considerably among acres in the region, as shown in figure 25. For the baseline conservation condition, the 43 percent of acres gaining soil organic carbon have an average annual gain of 82 pounds per acre per year. If conservation practices were not in use, only 33 percent of the acres would be gaining soil organic carbon and the annual rate of gain would be only 68 pounds per acre per year on those acres.

The average annual gain in soil organic carbon due to practices varies among acres, as shown in figure 26, depending on the extent to which residue and nutrient management is used, as well as the soil's potential to sequester carbon.

Some of the increased gain in soil organic carbon due to conservation practices is the result of soil erosion control—keeping soil organic carbon on the field promotes soil quality. If conservation practices were not in use, loss of soil organic carbon due to wind and water erosion would average 180 pounds per acre per year, compared to 152 pounds per acre with conservation practices (table 16).

For air quality concerns, the analysis centers on the decrease in CO2 emissions. Soils gaining carbon are obviously diminishing emissions, but so are soils that continue to lose carbon but at a slower rate. For all cropped acres, the reduction in soil organic carbon of 41 pounds per acre due to conservation practice use is equivalent to a CO2 emission reduction of 0.32 million U.S. tons of carbon dioxide for the Chesapeake Bay region.

Figure 25. Estimates of average annual change in soil organic carbon for cropped acres in the Chesapeake Bay region

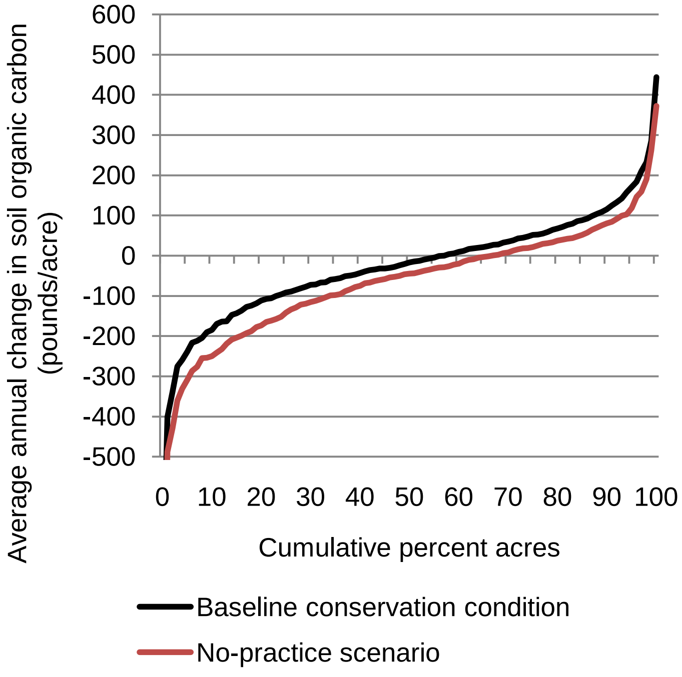
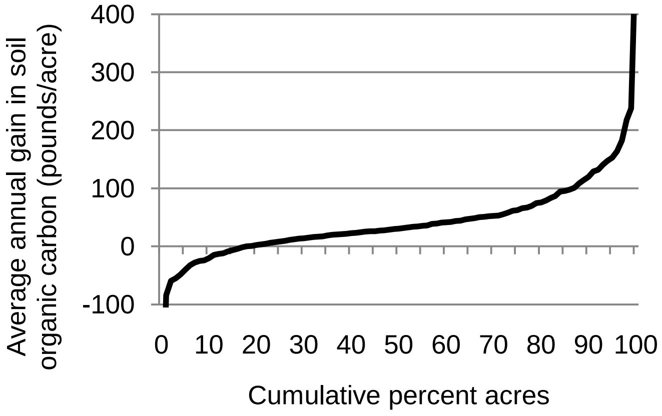


Figure 26. Estimates of average annual gain in soil organic carbon due to the use of conservation practices on cropped acres in the Chesapeake Bay region

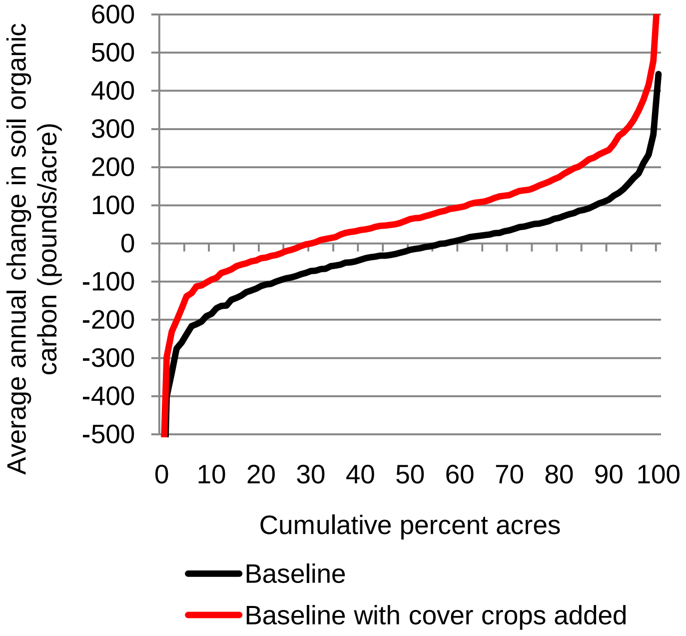


Note: About 18 percent of the acres have a higher soil organic carbon increase in the no-practice scenario than the baseline conservation condition because of the higher fertilization rates, including manure application rates, used in the no-practice scenario to simulate the effects of nutrient management practices.

Effects of cover crops on soil organic carbon change

The "what if" scenario that simulated the full adoption of cover crops on all cropped acres showed that soil organic carbon levels would increase on more cropped acres and decrease more slowly on other cropped acres (see Appendix C). The annual change in soil organic carbon would average about 97 pounds per acre higher than the 2003–06 baseline. Figure 27 shows that if cover crops were added to all cropped acres, 27 percent of cropped acres would move from losing soil organic carbon to gaining soil organic carbon, bringing acres that are gaining soil organic carbon to 70 percent of cropped acres in the region.

Figure 27. Estimates of average annual change in soil organic carbon for cropped acres, comparing the baseline scenario to a "what if" scenario with cover crops added to all cropped acres, Chesapeake Bay region

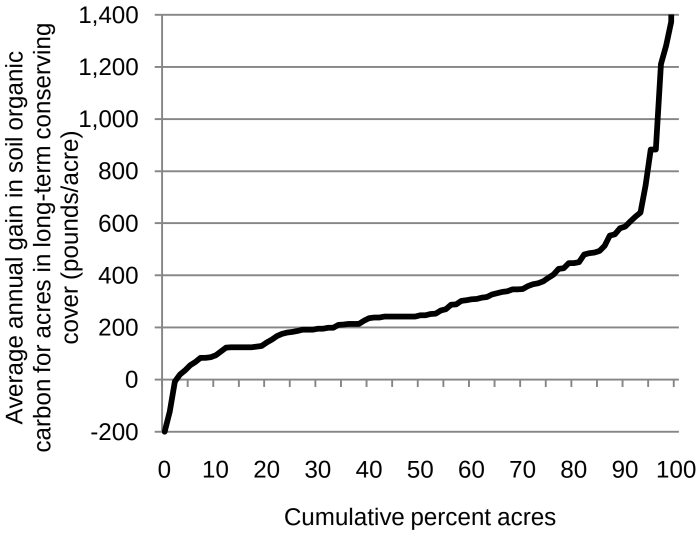


Land in long-term conserving cover

For land in long-term conserving cover, the annual change in soil organic carbon for the baseline conservation condition averages 233 pounds per acre per year (table 16). If these acres were still being cropped without any conservation practices, the annual average change in soil organic carbon would be a loss of 100 pounds per acre per year.

For these 100,000 acres, the gain in soil organic carbon averages 333 pounds per acre compared to a cropped condition without conservation practices. This is equivalent to a CO2 emission reduction of 0.06 million U.S. tons of carbon dioxide for the region. However, the rate of emission reduction due to conservation practices varies considerably among acres in long-term conserving cover, as shown in figure 28.

Figure 28. Estimates of average annual gain in soil organic carbon due to conversion to long-term conserving cover in the Chesapeake Bay region



Note: About 2 percent of the acres in long-term conserving cover have decreases in annual carbon gain compared to a cropped condition. Biomass production under long-term conserving cover is typically nitrogen limited. The higher biomass production and resulting crop residue from the fertilization of cropped acres can exceed the carbon benefits of long-term conserving cover under some conditions.

Effects of Practices on Nitrogen Loss

Baseline condition for cropped acres

Plant-available nitrogen sources include application of commercial fertilizer, application of manure, nitrogen produced by legume crops (soybeans, alfalfa, beans, and peas), a small amount of manure deposited by grazing livestock, and atmospheric nitrogen deposition. In total, these sources provide about 130 pounds of nitrogen per acre per year for cropped acres in the Chesapeake Bay region (table 17). Model simulations show that about 64 percent of this (84 pounds per acre) is taken up by the crop and removed at harvest in the crop yield, on average, and the remainder is lost from the field through various pathways.

For the baseline conservation condition, the annual average amount of total nitrogen lost from the field, other than the nitrogen removed from the field at harvest, is about 50 pounds per acre. These nitrogen loss pathways are (fig. 29)—

- nitrogen lost due to volatilization associated primarily with fertilizer and manure application (average of 6.9 pounds per acre per year);
- nitrogen returned to the atmosphere through denitrification processes (average of 1.6 pounds per acre per year);
- nitrogen lost with windborne sediment (average of 0.2 pounds per acre per year);
- nitrogen lost with surface runoff, including nitrogen lost with waterborne sediment (average of 8.8 pounds per acre per year); and
- nitrogen loss in subsurface flow pathways (average of 32.7 pounds per acre per year).

The two pathways that impact water quality directly—surface water *and* subsurface flows (average of 41.5 pounds/acre per year) —account for 83 percent of the total nitrogen loss in this region. Most of the nitrogen loss in subsurface flows returns to surface water through drainage ditches, tile drains, natural seeps, and groundwater return flow.

Model simulation results showed that nitrogen loss to specific pathways varies from acre to acre, as shown in figures 30 and 31. However, loss of nitrogen in subsurface flows is the dominant loss pathway for 80 percent of the cropped acres in the region. Nitrogen loss with waterborne sediment is the dominant loss pathway for 12 percent of the acres, and volatilization is the dominant loss pathway for 7 percent of the acres. Nitrogen loss in surface water (soluble) was the dominant loss pathway for only 1 percent of the cropped acres. Windborne nitrogen loss and denitrification were not dominant loss pathways for any cropped acres in the region.

Loss of nitrogen in subsurface flows can be quite high for some acres (fig. 30). Average annual losses of nitrogen in subsurface flows exceed 100 pounds per acre per year for the 7 percent of acres with the highest losses.

Acres receiving manure (38 percent of cropped acres) have, on average, twice the nitrogen loss as acres not receiving manure. Total nitrogen loss for acres receiving manure was 75 pounds per acre per year, compared to 35 pounds per acre per year for acres not receiving manure (table 17). Losses were also higher for highly erodible land (44 percent of cropped acres) than for non-highly erodible land.

Figure 29. Average annual nitrogen loss by loss pathway, Chesapeake Bay region

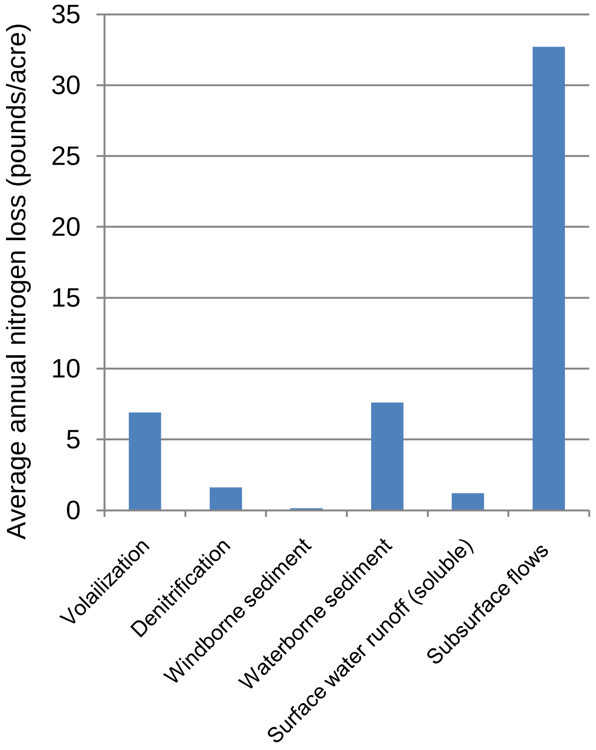


Figure 30. Cumulative distributions of average annual nitrogen lost through various loss pathways, Chesapeake Bay region

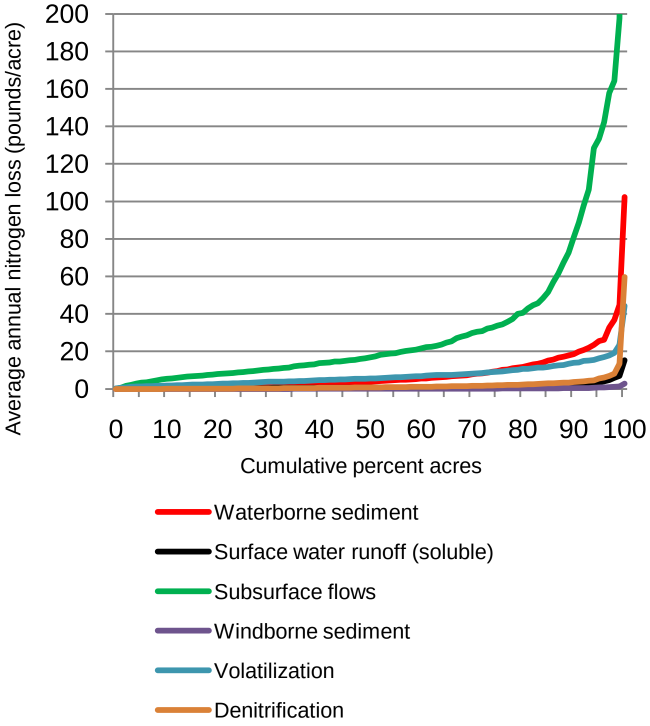
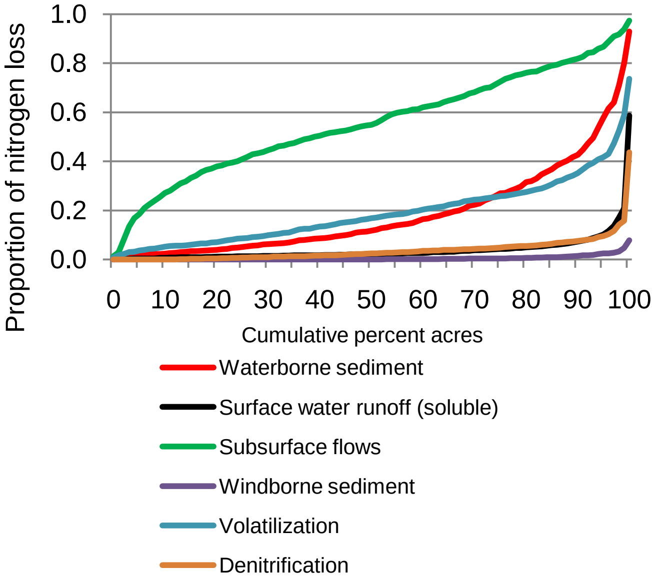


Figure 31. Cumulative distributions of proportions of nitrogen lost through six loss pathways, Chesapeake Bay region



Note: The horizontal axis consists of percentiles for each pathway; a given percentile for one curve will not represent the same acres on another curve.

Model simulations for the baseline conservation condition indicate that some cropped acres in the Chesapeake Bay region are much more susceptible to the effects of weather than other acres and lose much higher amounts of nitrogen (fig. 32). About 30 percent of the acres lose less than 40 pounds per acre per year through the various loss pathways under *all* weather conditions. About 25 percent of the acres, on the other hand, lose more than 100 pounds per acre in at least some years, and more than 40 pounds per acre in almost every year. In years with the most extreme weather, up to 5 percent of the acres lose over 300 pounds of nitrogen. Figure 32 also shows that nitrogen loss for the 20 percent of the cropped acres with the highest losses varies dramatically from year to year when compared to the 40 percent with the lowest total nitrogen loss.

The *average annual* total nitrogen loss for the baseline is shown in figure 33. Acres with the highest nitrogen losses have the highest inherent vulnerability combined with inadequate nutrient management and runoff controls. About 59 percent of cropped acres lose less than 40 pounds per acre per year, while 10 percent lose more than 100 pounds per acre per year.

Table 17. Field-level effects of conservation practices on nitrogen sources and nitrogen loss pathways for cropped acres in the Chesapeake Bay region

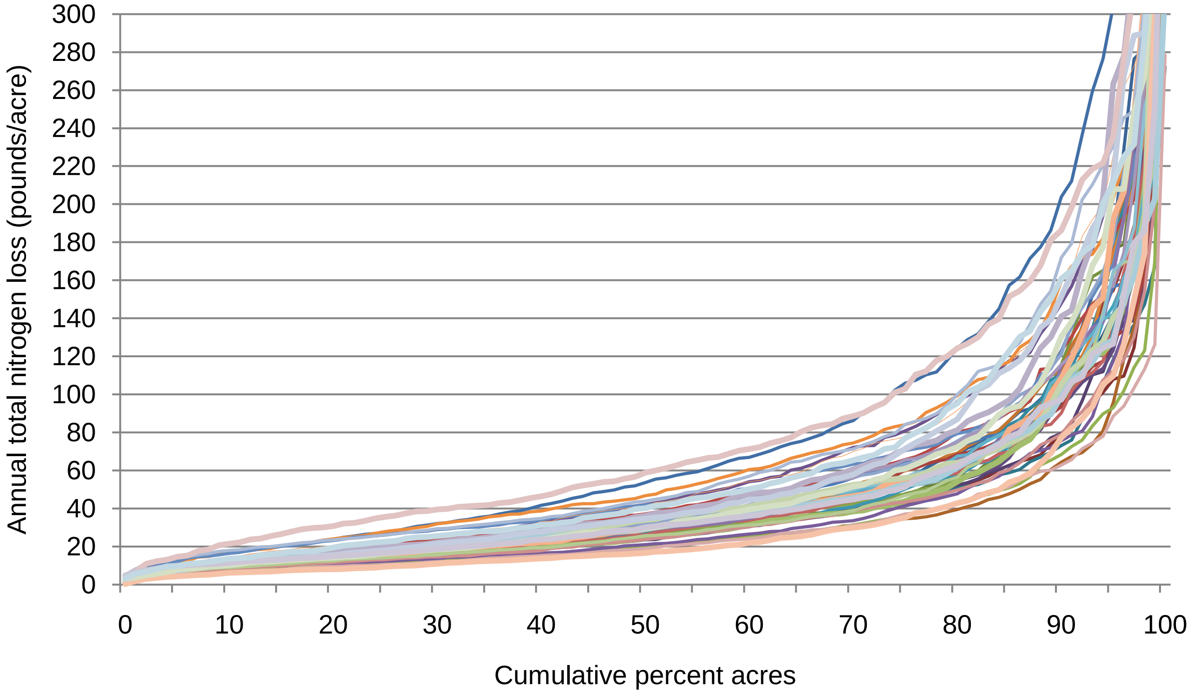
	Average annual values in pounds per acre			
Model simulated outcome	**Baseline conservation condition**	**No-practice scenario**	**Reduction due to practices**	**Percent reduction**
All cropped acres				
Nitrogen sources				
Atmospheric deposition	8.7	8.7	0.0	0
Bio-fixation by legumes	26.4	23.8	-2.6	-11
Nitrogen applied as commercial fertilizer and manure	95.3	123.8	28.5	23
All nitrogen sources	130.4	156.3	25.9	17
Nitrogen in crop yield removed at harvest	84.1	93.9	9.8*	10*
Nitrogen loss pathways				
Nitrogen loss by volatilization	6.9	6.1	-0.8**	-13**
Nitrogen loss through denitrification processes	1.6	1.2	-0.5**	-39**
Nitrogen lost with windborne sediment	0.2	0.3	0.1	42
Nitrogen loss with surface runoff, including waterborne sediment	8.8	15.1	6.3	42
Nitrogen loss with surface water (soluble)	1.2	3.1	1.9	61
Nitrogen loss with waterborne sediment	7.6	12.0	4.4	37
Nitrogen loss in subsurface flow pathways	32.7	47.3	14.6	31
Total nitrogen loss for all loss pathways	50.2	70.0	19.8	28
Change in soil nitrogen	-5.2	-8.7	-3.5	--
Highly erodible land (44 percent of cropped acres)				
All nitrogen sources	133	158	25.1	16
Total nitrogen loss for all loss pathways	60	83	22.9	27
Non-highly erodible land (56 percent of cropped acres)				
All nitrogen sources	128	155	26.6	17
Total nitrogen loss for all loss pathways	42	60	17.4	29
Acres with manure applied (38 percent of cropped acres)				
All nitrogen sources	160	193	32.9	17
Total nitrogen loss for all loss pathways	75	102	27.9	27
Acres without manure applied (62 percent of cropped acres)				
All nitrogen sources	112	134	21.7	16
Total nitrogen loss for all loss pathways	35	50	14.9	30

* The reduction in yield reflects the increase in nutrients in the representation in the no-practice scenario for nutrient management.

****** On about half of the cropped acres, more nitrogen volatilization and denitrification occurs with practices than without practices, resulting in only a small change in nitrogen volatilization and denitrification on average for the region due to conservation practices. In preventing nitrogen loss to other loss pathways, conservation practices keep more of the nitrogen compounds on the field longer, where it is exposed to wind and weather conditions that promote volatilization and denitrification.

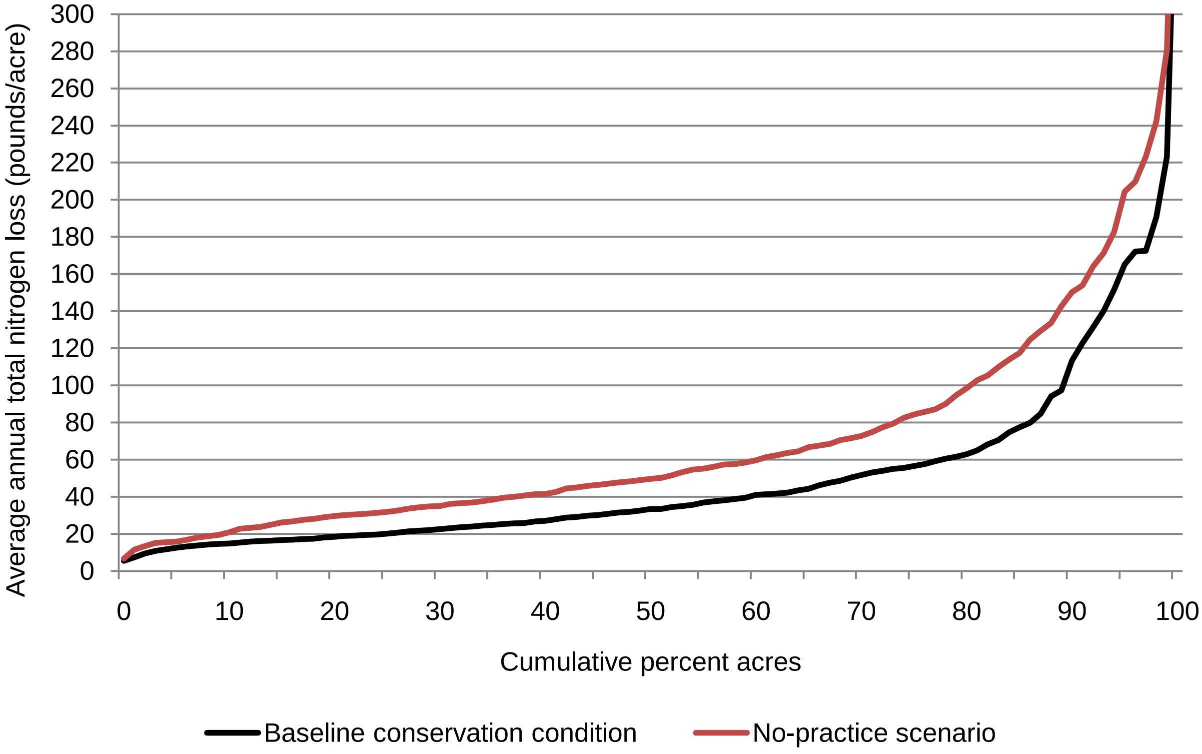
Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Model simulation results for the baseline conservation condition are presented in appendix B for the 4 subregions.

Figure 32. Distribution of annual total nitrogen loss for each year of the 47-year model simulation, Chesapeake Bay region



Note: This figure shows how annual total nitrogen loss (pounds per acre per year) varied within the region and from year to year in the model simulation for cropped acres. Each of the 47 curves shown above represents a single year of data and shows how annual total nitrogen loss varied over the region in that year, starting with the acres with the lowest total nitrogen loss and increasing to the acres with the highest total nitrogen loss. The family of curves shows how annual total nitrogen loss varied from year to year. The average annual curve for the baseline is shown in figure 33 (below).

Figure 33. Estimates of average annual total nitrogen loss for cropped acres in the Chesapeake Bay region



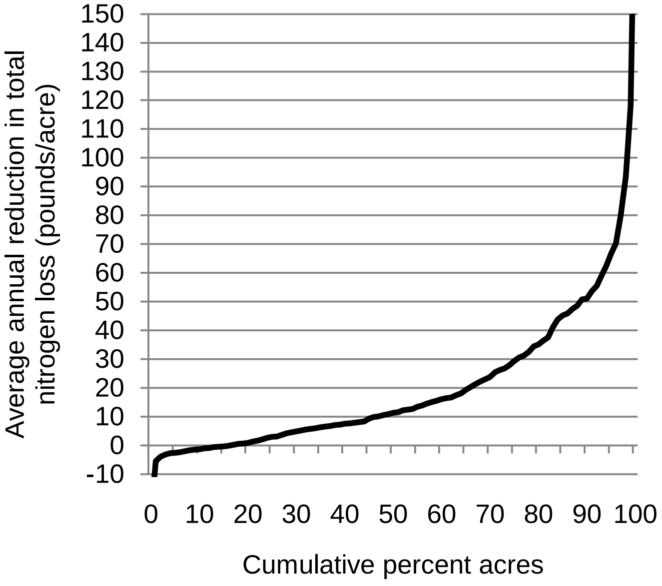
Effects of conservation practices on cropped acres

Model simulations show that the conservation practices in use in the region have reduced total nitrogen loss from cropped acres by an average of 20 pounds per acre per year, representing a 28 percent reduction, on average (table 17). Without conservation practices, about 64 percent of the cropped acres would have average annual total nitrogen loss exceeding 40 pounds per acre per year; with conservation practices, 40 percent of acres exceed this level of loss (fig. 33).

The effects of conservation practices vary from acre to acre (fig. 34). About half of the acres have average annual reductions in total nitrogen loss below 11 pounds per acre. In contrast, about 17 percent of the acres have reduced total nitrogen loss by an average of over 40 pounds per acre per year. These are acres with higher levels of treatment and often higher levels of nitrogen use in the no-practice scenario.

Figure 34 also shows that about 16 percent of the acres have an *increase* in total nitrogen loss due to conservation practice use. Most of these gains are small; only 2 percent of the acres have gains of more than 4 pounds per acre. This result primarily occurs on soils with relatively high soil nitrogen content and generally with low slopes where the surface water runoff is re-directed to subsurface flow by soil erosion control practices. The higher volume of water moving through the soil profile extracts more nitrogen from the soil than under conditions without conservation practices. Cropping systems that include legumes also have a higher soil nitrogen stock in the baseline conditions because legumes produce proportionately less biofixation of nitrogen under the higher fertilization rates simulated in the no-practice scenario.

Figure 34. Estimates of average annual reduction in total nitrogen loss due to the use of conservation practices on cropped acres in the Chesapeake Bay region



Note: See text for discussion of conditions that result in lower total nitrogen loss in the no-practice scenario than in the baseline conservation condition for 16 percent of the acres.

Nitrogen lost with surface runoff. Model simulations show that, on average, nitrogen lost with surface runoff has been reduced 42 percent due to use of conservation practices in the region (table 17). Without conservation practices, about 35 percent of the cropped acres would have nitrogen lost with surface runoff in excess of an average of 15 pounds per acre per year, compared to only 18 percent of the acres in the baseline conservation condition (fig. 35). Figure 36 shows that about 20 percent of the cropped acres have reductions in nitrogen lost with surface runoff greater than 10 pounds per acre due to conservation practice use. Figure 36 also shows, however, that about 60 percent of the acres have reductions less than 5 pounds per acre due to conservation practices.

Figure 35 Estimates of average annual nitrogen lost with surface runoff (including waterborne sediment) for cropped acres in the Chesapeake Bay region

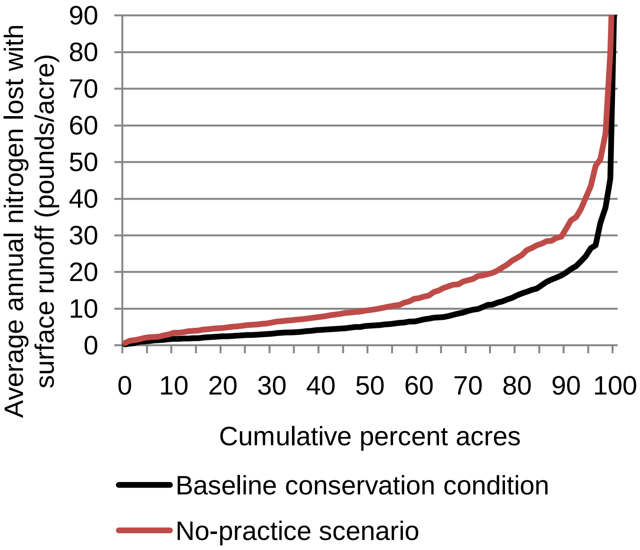
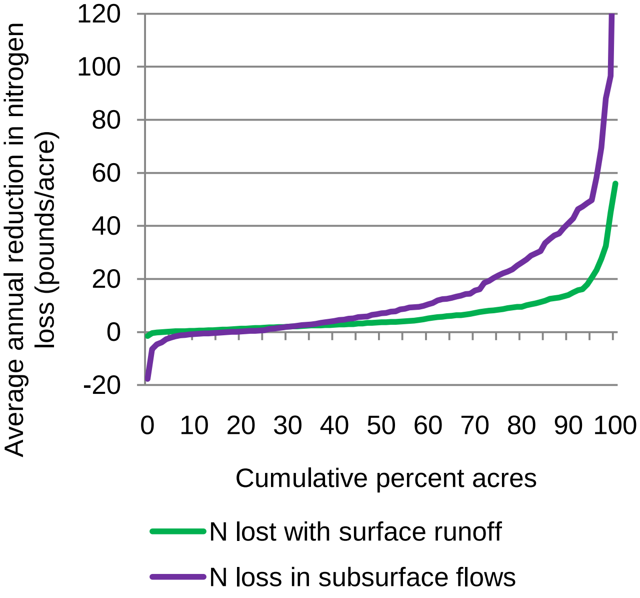


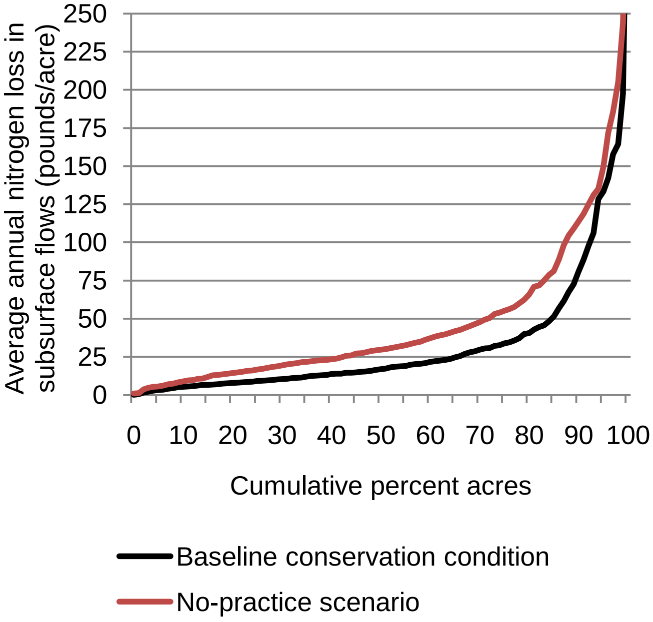
Figure 36. Estimates of average annual reduction in nitrogen lost with surface runoff and reduction in nitrogen loss in subsurface flows due to the use of conservation practices on cropped acres in the Chesapeake Bay region



Note: See text for discussion of negative reductions for loss of nitrogen in subsurface flows.

Nitrogen loss in subsurface flows. Conservation practices are effective in reducing nitrogen loss in subsurface flows on many acres, but make little difference on other acres and even result in small gains in nitrogen loss in subsurface flows for 17 percent of cropped acres (figs. 36 and 37). (Gains in nitrogen loss in subsurface flows are represented in figure 36 as negative reductions.) On average, conservation practices have reduced nitrogen loss in subsurface flows from 47 pounds per acre without practices to 33 pounds per acre with practices, representing an average reduction of 15 pounds per acre per year (31-percent reduction) (table 17). Figure 36 shows that reductions in nitrogen loss in subsurface flows exceed 30 pounds per acre for 15 percent of the cropped acres, on average, but are less than 5 pounds per acre for 42 percent of the acres.

Figure 37. Estimates of average annual nitrogen loss in subsurface flows for cropped acres in the Chesapeake Bay region



The gains in nitrogen loss due to conservation practices for 17 percent of the cropped acres are largely due to relatively weak nutrient management practices on acres with erosion control treatment. A portion of the reduction in nitrogen lost with surface runoff is re-routed to subsurface loss pathways, resulting in gains or only small reductions in nitrogen loss in subsurface flows. This re-routing of surface water runoff to subsurface flow pathways results in additional nitrogen being leached from the soil, diminishing and sometimes offsetting the overall positive effects of conservation practices on total nitrogen loss.

These model simulation results underscore the importance of pairing water erosion control practices with effective nutrient management practices so that the full suite of conservation practices will provide the environmental protection needed.

Tradeoffs in Conservation Treatment

Conservation practices applied on cropland are, for the most part, synergistic. The benefits accumulate as more practices are added to the designed systems. However, when only a single resource concern is addressed (such as soil erosion), antagonism between the practices and other resource concerns may occur. That is why it is essential that all resource concerns be considered during the conservation planning process. Most of the time the tradeoffs are much smaller than the magnitude of the primary resource concerns. Common examples are:

- Terraces and conservation tillage are planned to solve a serious water erosion problem. However, in some areas there may be concern about saline seeps at the lower part of the field. The planned practices will solve the erosion problem, but could exacerbate the saline seep problem under some conditions. Ignoring that fact does not make for an adequate conservation plan.
- Conservation tillage is planned for erosion control on a cropland field with a high water table. The reduction in runoff may increase leaching of nitrates into the shallow water table. This potential secondary problem requires additional nutrient management practices to address the concern.
- A nutrient management plan reduces the amount of manure added to a field to reduce the loss of nutrients to surface or groundwater. However, the reduction in organic material added to the field may reduce the soil organic matter or reduce the rate of change in soil organic matter.
- Figure 34 shows that about 16 percent of the acres have an increase in total nitrogen loss due to conservation practice use. This result occurs primarily on soils with relatively high soil nitrogen content and generally low slopes where the surface water runoff is re-directed to subsurface flow by soil erosion control practices. The higher volume of water moving through the soil profile extracts more nitrogen from the soil than under conditions without conservation practices. For these fields, the nutrient management component of a farmer's conservation plan would need to be enhanced to reduce or eliminate the negative effects of soil erosion control practices on nitrogen loss.

A *comprehensive planning process* is used to identify the appropriate combination of practices needed to address multiple resource concerns by taking into account the specific inherent vulnerabilities associated with each field. To ensure that proper consideration is given to the effects of conservation practices on *all* of the resource concerns, USDA/NRCS developed a comprehensive planning tool referred to as CPPE (Conservation Practice Physical Effects). The CPPE is included in the Field Office Technical Guide. Conservation planners are expected to use CPPE as a reference to ensure that *all* resource concerns are addressed in conservation plans.

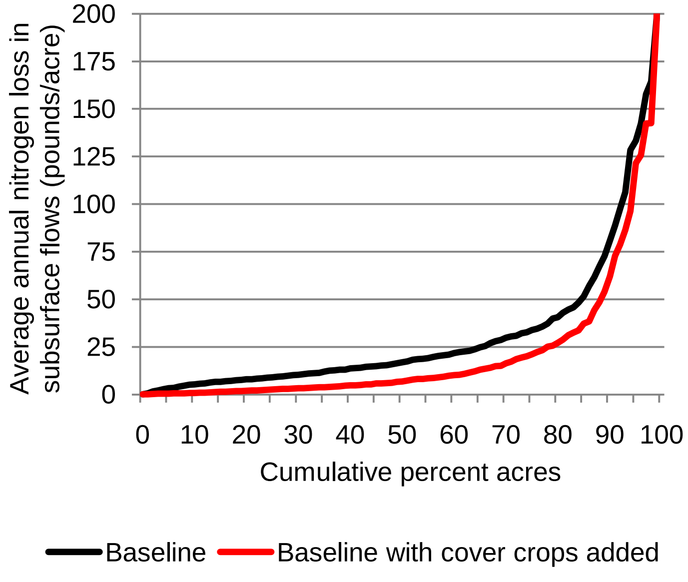
Effects of cover crops on nitrogen loss. A “what if” scenario that simulated the use of cover crops on all cropped acres was conducted to demonstrate the potential for cover crops to reduce sediment and nutrient loss from fields in this region (see Appendix C). Results showed that full adoption of cover crops in this region would further reduce total nitrogen loss by 19 percent compared to the 2003–06 baseline condition, bringing the average annual total nitrogen loss for the region to about 40.5 pounds per acre per year. Cover crops were most effective in reducing the two loss pathways that impact water quality. Full adoption of cover crops on all acres would—

- reduce nitrogen loss with surface runoff, including waterborne sediment, an average of 4.0 pounds per acre per-year (from 8.8 to 4.8 pounds per acre), representing a 46 percent decrease; and
- reduce nitrogen loss in subsurface flow pathways an average of 10 pounds per acre per year (from 33 to 23 pounds per acre), representing a 31-percent decrease.

The largest reductions due to full adoption of cover crops was for nitrogen loss in subsurface flow pathways (figs. 38 and 39). While all reductions in nitrogen loss due to cover crop use are significant, they are not uniform across all cropped acres. For nitrogen loss in subsurface flows, 30 percent of the acres would be expected to have loss reductions less than 5 pounds per acre, while about 10 percent of the acres would be expected to have loss reductions greater than 20 pounds per acre.

Even after full adoption of cover crops, however, about 20 percent of cropped acres in the region will have average annual losses of nitrogen in subsurface flows above 25 pounds per acre. These acres will require comprehensive nutrient management to bring losses down to acceptable levels.

Figure 38. Estimates of average annual nitrogen loss in subsurface flows for cropped acres, comparing the baseline scenario to a “what if” scenario with cover crops added to all cropped acres, Chesapeake Bay region



Land in long-term conserving cover

Total nitrogen loss has been reduced by about 88 percent on the 0.1 million acres in long-term conserving cover, compared to conditions that would be expected had the acres remained in crops. Converting cropped acres to long-term conserving cover is very effective in reducing total nitrogen loss, as demonstrated in figure 40 and table 18, although the reductions are much higher for some acres than others. Conversion of cropped acres to long-term conserving cover in the region has reduced nitrogen loss in subsurface flows from these acres by an average loss of 59 pounds per acre per year to about 3 pounds per acre per year, a reduction of 95 percent.

Figure 39. Estimates of the average annual potential reduction in nitrogen loss in subsurface flows if cover crops were used on all cropped acres in the Chesapeake Bay region

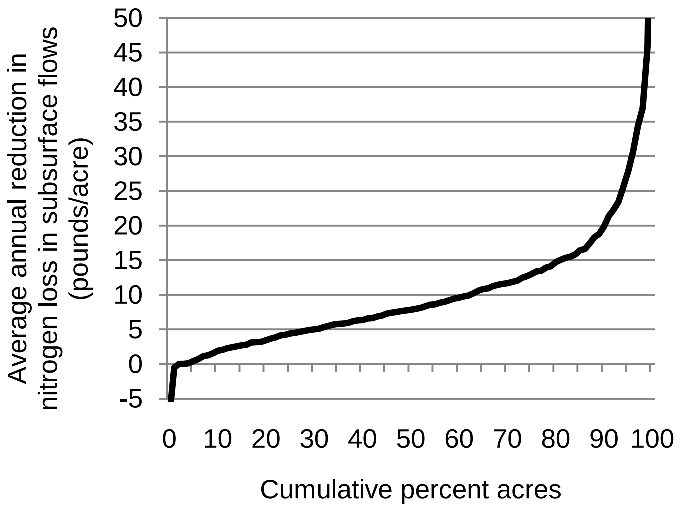


Figure 40. Estimates of average annual total nitrogen loss for land in long-term conserving cover in the Chesapeake Bay region

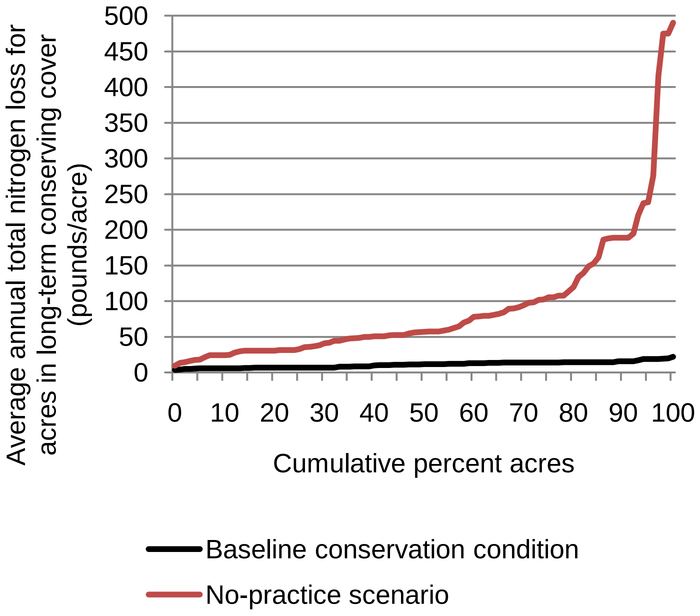


Table 18. Effects of conservation practices on nitrogen sources and nitrogen loss pathways for land in long-term conserving cover, Chesapeake Bay region

	Average annual values in pounds per acre			
Model simulated outcome	**Baseline conservation condition**	**No-practice scenario**	**Reduction due to practices**	**Percent reduction**
Nitrogen sources				
Atmospheric deposition	9.8	9.8	0.0	0
Bio-fixation by legumes	11.5	21.7	10.2	47
Nitrogen applied as commercial fertilizer and manure	0.0	132.8	132.8	100
All nitrogen sources	21.3	164.3	143.0	87
Nitrogen in crop yield removed at harvest	1.5*	84.7	83.2	98
Nitrogen loss pathways				
Nitrogen loss by volatilization	5.2	6.2	0.9	15
Nitrogen loss through denitrification processes	2.4	2.8	0.4	15
Nitrogen lost with windborne sediment	0.00	0.03	0.03	100
Nitrogen loss with surface runoff, including waterborne sediment	0.6	21.7	21.1	97
Nitrogen loss with surface water (soluble)	0.3	3.2	2.9	91
Nitrogen loss with waterborne sediment	0.4	18.5	18.2	98
Nitrogen loss in subsurface flow pathways	2.9	59.3	56.3	95
Total nitrogen loss for all pathways	11.2	90.0	78.8	88
Change in soil nitrogen	7.6	-11.8	-19.4	--

* Harvest was simulated on acres planted to trees where expected tree age is less than the 47-years included in the model simulation. At tree harvest time, the grass also is removed and replanted.

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text.

Effects of Practices on Phosphorus Loss

Phosphorus, like nitrogen, is an essential element needed for crop growth. Unlike nitrogen, however, phosphorus rarely occurs in a gaseous form so the agricultural model has no atmospheric component. Only phosphorus compounds that are soluble in water are available for plants to use. Although total phosphorus is plentiful in the soil, only a small fraction is available at any one time for plant uptake. Farmers apply commercial phosphate fertilizers to supplement low quantities of plant-available phosphorus in the soil.

Baseline condition for cropped acres

In the model simulations for the Chesapeake Bay region, about 25 pounds per acre of phosphorus were applied as commercial fertilizer or in manure to cropped acres, on average, in each year of the model simulation (table 19). About half of the phosphorus applied is taken up by the crop and removed at harvest—13 pounds per acre per year, on average.

Total phosphorus loss for all loss pathways averaged 3.8 pounds per acre per year in the baseline conservation condition (table 19). These phosphorus loss pathways are—

- phosphorus lost with windborne sediment (average of 0.03 pound per acre per year);
- phosphorus lost with waterborne sediment (average of 1.8 pounds per acre per year);
- soluble phosphorus lost to surface water, including soluble phosphorus in surface water runoff, and soluble phosphorus that infiltrates into the soil profile but quickly returns to surface water either through quick return lateral flow or intercepted by drainage systems (average of 1.9 pounds per acre per year); and
- soluble phosphorus that percolates through the soil profile into the groundwater (average of 0.07 pound per acre per year).

Nearly all (98 percent) of phosphorus loss from fields in the Chesapeake Bay region is either with waterborne sediment (55 percent) or soluble phosphorus lost to surface water (43 percent) (fig. 41), and these two loss pathways are approximately equal in importance. The percent of phosphorus lost in each loss pathway varies from acre to acre, as shown in figure 42 for cropped acres. Soluble phosphorus loss with surface water runoff and lateral flow (including discharge to drainage ditches) was the dominant loss pathway for 59 percent of cropped acres. The dominant loss pathway for the remaining 41 percent of cropped acres is phosphorus lost with waterborne sediment. A very small amount of soluble phosphorus is lost through percolation into groundwater—2 percent of the total phosphorus loss.

As shown for nitrogen, total phosphorus losses are much higher for acres receiving manure than for acres that did not receive manure (table 19). Phosphorus losses are also much higher for highly erodible land than for non-highly erodible land.

Model simulations for the baseline conservation condition indicate that some cropped acres in the Chesapeake Bay region lose much higher amounts of phosphorus than other acres (figs. 43 and 44). About half of the acres lose less than 4 pounds per acre per year through the various loss pathways under *all* weather conditions. About one-fourth of the acres, on the other hand, lose more than 12 pounds per acre in at least some years.

Figure 41. Estimates of average annual phosphorus lost through various loss pathways, Chesapeake Bay region

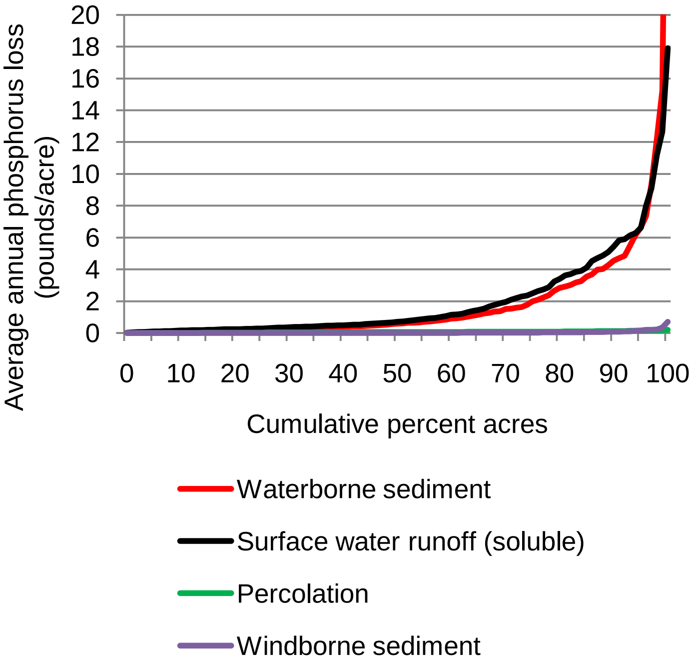


Figure 42. Cumulative distributions of the proportion of phosphorus lost through various loss pathways, Chesapeake Bay region

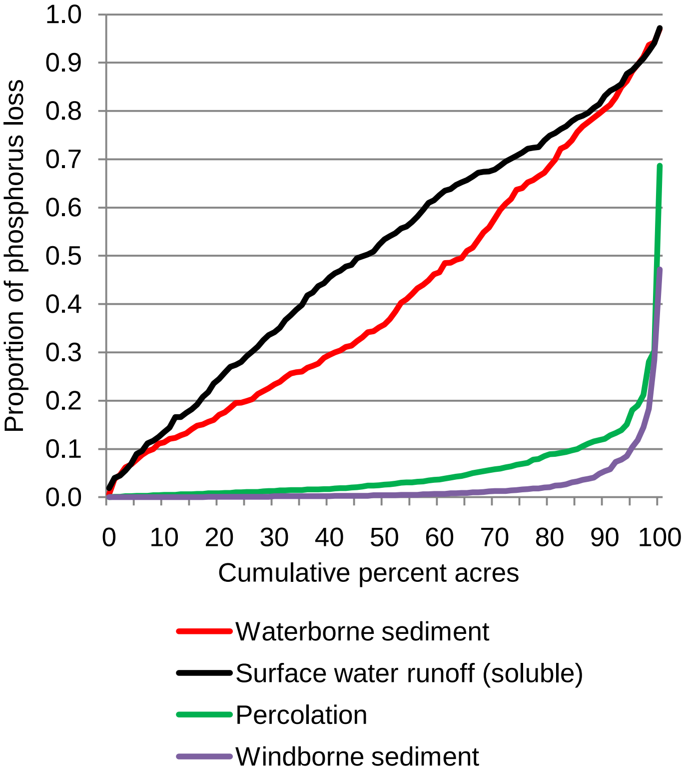


Table 19. Field-level effects of conservation practices on phosphorus sources and phosphorus loss pathways for cultivated cropland in the Chesapeake Bay region

	Average annual values in pounds per acre			
Model simulated outcome	**Baseline conservation condition**	**No-practice scenario**	**Reduction due to practices**	**Percent reduction**
Cropped acres (4.3 million acres)				
Phosphorus sources				
Phosphorus applied as commercial fertilizer and manure	25.2	33.7	8.5	25
Phosphorus in crop yield removed at harvest	13.28	14.40	1.12	8
Phosphorus loss pathways				
Phosphorus lost with windborne sediment	0.03	0.08	0.05	59
Phosphorus lost to surface water (sediment attached and soluble)*	3.67	6.17	2.51	41
Soluble phosphorus lost to surface water*	1.89	2.64	0.74	28
Phosphorus loss with waterborne sediment	1.77	3.54	1.76	50
Soluble phosphorus loss to groundwater	0.07	0.07	0.00	0
Total phosphorus loss for all loss pathways	3.77	6.33	2.56	40
Change in soil phosphorus	8.11	12.97	4.86	--
Highly erodible land (44 percent of cropped acres)				
Phosphorus applied as commercial fertilizer and manure	27.6	34.0	6.4	19
Total phosphorus loss for all loss pathways	5.3	8.3	3.06	37
Non-highly erodible land (56 percent of cropped acres)				
Phosphorus applied as commercial fertilizer and manure	23.4	33.5	10.1	30
Total phosphorus loss for all loss pathways	2.6	4.7	2.16	45
Acres with manure applied (38 percent of cropped acres)				
Phosphorus applied as commercial fertilizer and manure	39.3	46.8	7.5	16
Total phosphorus loss for all loss pathways	6.2	9.2	3.03	33
Acres without manure applied (62 percent of cropped acres)				
Phosphorus applied as commercial fertilizer and manure	16.7	25.8	9.1	35
Total phosphorus loss for all loss pathways	2.3	4.6	2.27	50
Land in long-term conserving cover (0.1 million acres)				
Phosphorus sources				
Phosphorus applied as commercial fertilizer and manure	0.0	35.4	35.4	100
Phosphorus in crop yield removed at harvest	0.51**	12.98	12.47	96
Phosphorus loss pathways				
Phosphorus lost with windborne sediment	0.00	0.01	0.01	100
Phosphorus lost to surface water (sediment attached and soluble)*	0.49	7.89	7.39	94
Soluble phosphorus lost to surface water*	0.46	2.75	2.30	83
Phosphorus loss with waterborne sediment	0.04	5.13	5.09	99
Soluble phosphorus loss to groundwater	0.12	0.08	-0.03	-40
Total phosphorus loss for all loss pathways	0.61	7.98	7.37	92
Change in soil phosphorus	-1.48	14.44	15.92	--

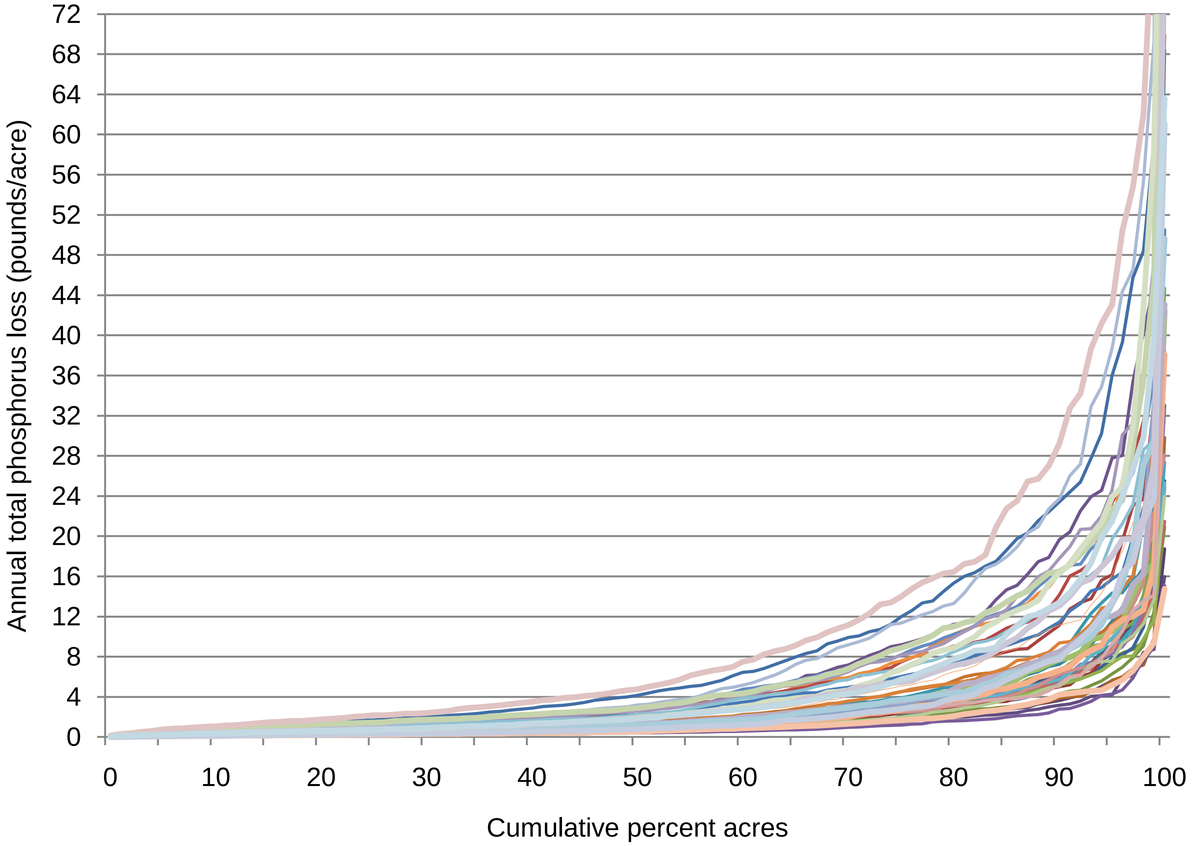
* Soluble phosphorus lost to surface water includes phosphorus in water moving laterally within the soil into drainage systems (tile and surface drainage) and natural seeps.

** Harvest was simulated on acres planted to trees where expected tree age is less than the 47-years included in the model simulation. At tree harvest time, the grass also is removed and replanted.

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text.

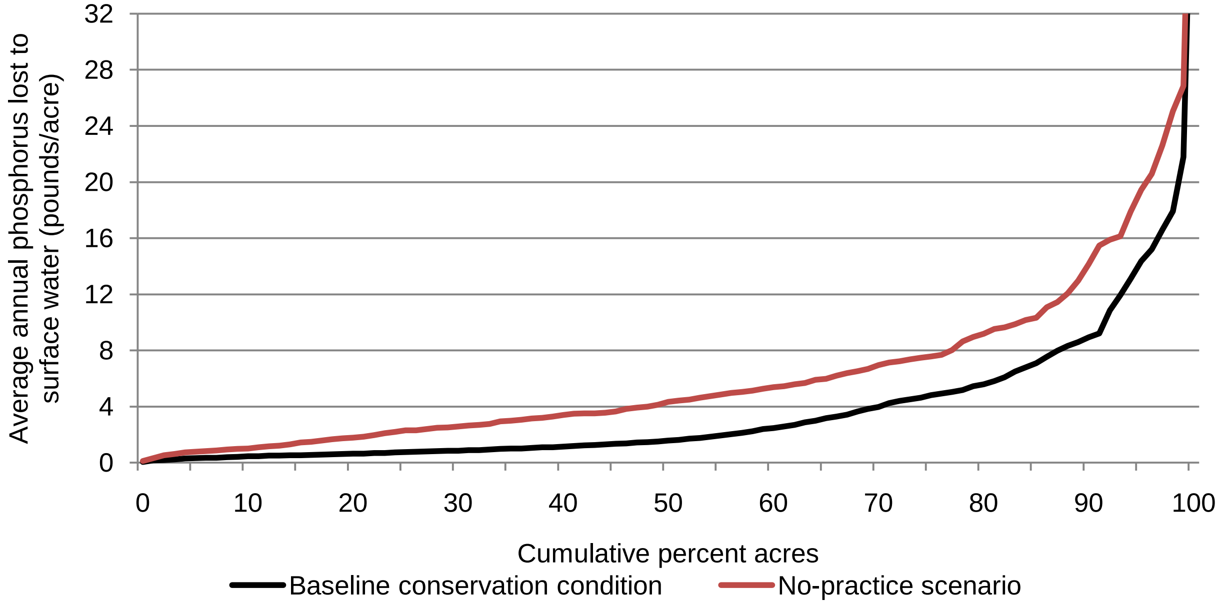
Note: Model simulation results for the baseline conservation condition are presented in appendix B for the 4 subregions.

Figure 43. Distribution of annual total phosphorus loss for each year of the 47-year model simulation, Chesapeake Bay region



Note: This figure shows how annual total phosphorus loss (pounds per acre per year) varied within the region and from year to year in the model simulation on cropped acres. Each of the 47 curves shown above represents a single year of data and shows how annual total phosphorus loss varied over the region in that year, starting with the acres with the lowest total phosphorus loss and increasing to the acres with the highest total phosphorus loss. The family of curves shows how annual total phosphorus loss varied from year to year.

Figure 44. Estimates of average annual phosphorus lost to surface water (sediment attached and soluble)*for cropped acres in the Chesapeake Bay region



***** Soluble phosphorus lost to surface water includes phosphorus in water moving laterally within the soil into drainage systems (tile and surface drainage) and natural seeps.

Effects of conservation practices on cropped acres

Conservation practices have reduced total phosphorus lost to surface water for cropped acres by 41 percent, reducing the average loss from 6.2 pounds per acre per year if conservation practices were not in use to 3.7 pounds per acre per year for the baseline conservation condition (table 19). The effects of conservation practices on phosphorus lost to surface water (soluble and sediment attached) are shown in figures 44 and 45 for cropped acres. With the conservation practices in use as represented by the baseline conservation condition, about 30 percent of cropped acres exceed 4 pounds per acre per year, on average. Without those practices in use, phosphorus lost to surface water would exceed 4 pounds per acre for 52 percent of the acres.

The effects of conservation practices on phosphorus lost to surface water vary considerably throughout the Chesapeake Bay region, as shown in figure 45. Reductions due to practices are less than 2 pounds per acre for half of the cropped acres. At the high end, reductions exceed 6 pounds per acre for about 10 percent of the acres.

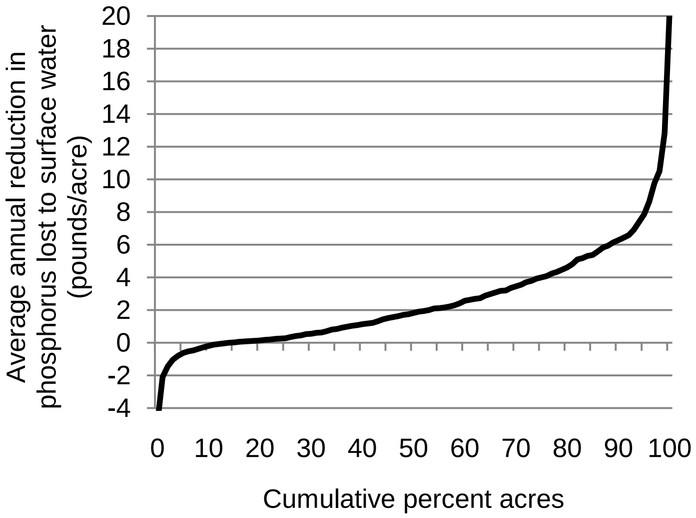
Effects of cover crops on phosphorus loss

The “what if” scenario simulating the use of cover crops on all cropped acres (see Appendix C) found that cover crops were also helpful in reducing phosphorus losses. Results showed that full adoption of cover crops in this region would further reduce total phosphorus loss from an average of 3.8 pounds per acre per year to 2.6 pounds per acre per year, representing a 32-percent decrease compared to the 2003–06 baseline condition. About half of the acres would be expected to have loss reductions less than 0.5 pound per acre, while about 15 percent of the acres would be expected to have loss reductions greater than 2 pounds per acre. (See figs. C11 and C12 in Appendix C.)

Land in long-term conserving cover

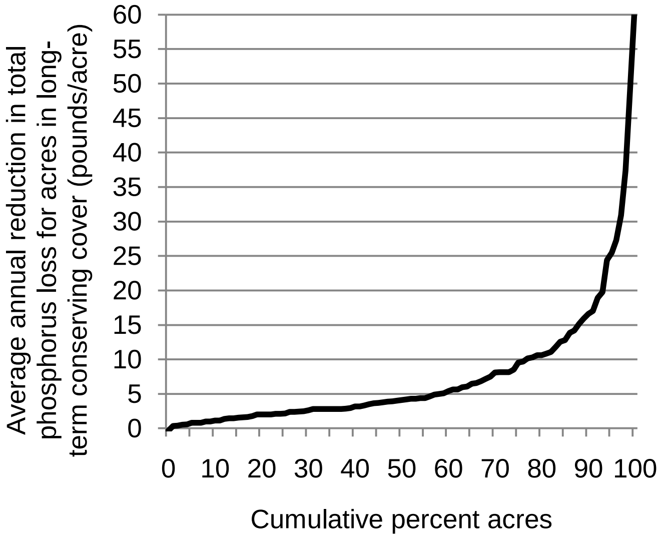
For land in long-term conserving cover, total phosphorus loss is 92 percent less than it would have been if crops had been grown and no conservation practices used, reducing total phosphorus loss by 7.4 pounds per acre per year, on average (table 19 and figure 46). Reductions vary among the acres in the region; reductions are less than 2 pounds per acre for about 20 percent of the acres in long-term conserving cover.

Figure 45. Estimates of average annual reduction in phosphorus lost to surface water (sediment attached and soluble) due to conservation practices on cropped acres in the Chesapeake Bay region



Note: Acres with an overall increase in surface water runoff due to conservation practices (see figure 16) causes gains (negative reductions) greater than 0.1 pounds per acre in phosphorus lost to surface water due to conservation practices for about 11 percent of the cropped acres.

Figure 46. Estimates of average annual reduction in total phosphorus loss due to conversion to long-term conserving cover in the Chesapeake Bay region



Effects of Practices on Pesticide Residues and Environmental Risk

Use of pesticides to protect crops from weeds, insects, and diseases is an integral part of crop production. While pesticides are essential for large-scale agriculture, pesticide residues can migrate from the application site and lead to unintentional risk to humans and non-target plants and animals. Most pesticides are applied at much lower rates than nutrients. The fraction of pesticides applied that migrates offsite with water is generally less than 1 to 2 percent. Nevertheless, small amounts of pesticide residue can create water quality concerns depending on the toxicity of the pesticide residues to non-target species and even exceed EPA drinking water standards at times.

Baseline condition for pesticide loss

The APEX model tracks the mass loss of pesticides dissolved in surface water runoff, adsorbed to sediment loss from water erosion, and dissolved in subsurface flow pathways.[15] The distribution of losses through each of these three pathways is contrasted in figure 47. All three pathways are important in the transport of pesticide residues from fields. Waterborne sediment accounted for about 37 percent of the total mass loss, followed by pesticides dissolved in surface water runoff at 36 percent and pesticides in subsurface flows at 27 percent.

In the Chesapeake Bay region, the dominant loss pathway for 37 percent of cropped acres was pesticides dissolved in surface water runoff. Waterborne sediment was the dominant pesticide loss pathway for 34 percent of the acres, and subsurface flow s were the dominant pesticide loss pathway for 20 percent of the acres. The remaining 9 percent of the acres had no pesticide loss.

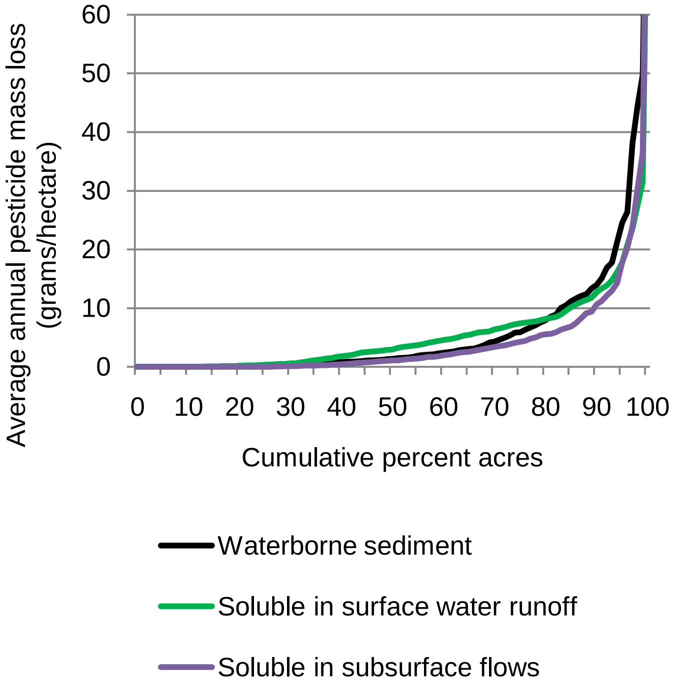
The average annual amount of pesticide lost from farm fields in the Chesapeake Bay region is about 15 grams of active ingredient per hectare per year (table 20).[16] As was observed for sediment and nutrient loss, the majority of pesticide loss occurs on a minority of acres within the Chesapeake Bay region (fig. 47). About 64 percent of the acres have total mass loss less than the mean value of 15 grams per hectare. The median loss is 9.4 grams per hectare.

In the model simulations, the pesticide applied in the largest amount throughout the region was atrazine at 24 percent of the total weight of pesticides applied, followed closely by glyphosate at 21 percent (table 21). The herbicide S-metolachlor represented 14 percent of the total weight of pesticides applied in the region. These three pesticides accounted for 59 percent of the pesticides applied in the region, by weight.

The most common pesticide residues lost from farm fields are atrazine (33 percent of total mass loss), paraquat dichloride (15 percent of total mass loss), and S-metolachlor (11 percent of total mass loss) (table 21). Pendimethalin, glyphosate, and Simazine each represented over 5 percent of the total mass loss. These six pesticides represented 80 percent of all pesticide residues lost from fields in the model simulations for the Chesapeake Bay region.

Pesticide loss for land in long-term conserving cover was not simulated because the survey did not provide information on pesticide use on land enrolled in CRP General Signups. It was assumed that there was no pesticide residues lost from land in long-term conserving cover.

Figure 47. Estimates of average annual pesticide loss (mass loss of all pesticides combined) for three loss pathways, Chesapeake Bay region



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[15] The APEX model currently does not estimate pesticides lost in spray drift or volatilization.

[16] Grams per hectare is the standard reporting unit for pesticide active ingredients.

Table 20. Field-level effects of conservation practices on pesticide loss and associated edge-of-field environmental risk for cropped acres in the Chesapeake Bay region

Model simulated outcome	Baseline conservation condition	No-practice scenario	Reduction due to practices	Percent reduction
Pesticide sources				
Average annual amount of pesticides applied (grams of active ingredient/hectare)	2000	2285	285	12
Pesticide loss				
Average annual mass loss of pesticides for all pathways (grams of active ingredient/hectare)	15	20	5	26
Edge-of-field pesticide risk indicator				
Average annual surface water pesticide risk indicator for aquatic ecosystems	1.76	2.32	0.56	24
Average annual surface water pesticide risk indicator for humans	0.42	0.54	0.12	22
Average annual groundwater pesticide risk indicator for humans	0.36	0.48	0.11	24

Note: It was assumed that no pesticides were applied to land in long-term conserving cover and there was no data on residual pesticides in the soil for these acres; thus, the assessment of the effects of this practice on pesticide loss was not done.

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Model simulation results for the baseline conservation condition are presented in appendix B for the 4 subregions.

Table 21. Dominant pesticides applied in model simulations and contributing to losses, Chesapeake Bay region

Pesticide (active ingredient name)	Pesticide type	Percent of total applied in the region
Pesticide application*		
Atrazine	Herbicide	24
Glyphosate, isopropylamine salt	Herbicide	21
S-Metolachlor	Herbicide	14
Simazine	Herbicide	6
Pendimethalin	Herbicide	5
Metolachlor	Herbicide	4
Acetochlor	Herbicide	4
Paraquat dichloride	Herbicide	3
2,4-D, 2-ethylhexyl ester	Herbicide	1
Glyphosate	Herbicide	1
Alachlor	Herbicide	1
Metam-sodium	Multi-purpose	1
Glyphosate-trimesium	Insecticide	1
1,3-Dichloropropene	Fungicide	1
Total		88
		Percent of total pesticide loss in the region**
Pesticide loss from farm fields*		
Atrazine	Herbicide	33
Paraquat dichloride	Herbicide	15
S-Metolachlor	Herbicide	11
Pendimethalin	Herbicide	8
Glyphosate, isopropylamine salt	Herbicide	7
Simazine	Herbicide	6
Metolachlor	Herbicide	5
Sulfentrazone	Herbicide	3
Acetochlor	Herbicide	2
2,4-D 2-ethylhexyl ester	Herbicide	1
Trifluralin	Herbicide	1
Total		91

* Pesticides not listed each represented less than 1 percent of the total. Percents may not add to total due to rounding.

** Includes loss of pesticides dissolved in surface water runoff, adsorbed to sediment loss from water erosion, and dissolved in subsurface flow pathways.

Effects of conservation practices on pesticide residues and risk

Management practices that reduce the potential for loss of pesticides from farm fields consist of a combination of Integrated Pesticide Management (IPM) techniques and water erosion control practices. Water erosion control practices mitigate the loss of pesticides from farm fields by reducing surface water runoff and sediment loss, both of which carry pesticide residues from the farm field to the surrounding environment. IPM is site-specific in nature, with individual tactics determined by the particular crop/pest/environmental condition. IPM consists of a management strategy for prevention, avoidance, monitoring, and suppression of pest populations. When the use of pesticides is necessary to protect crop yields, selection of pesticides that have the least environmental risk is an important aspect of the suppression component of IPM.

Model simulations show that conservation practices—primarily water erosion control practices—are effective in reducing the loss of pesticide residues from farm fields. Use of conservation practices has reduced the loss of pesticides (summed over all pesticides) by an average of 5 grams of active ingredient per hectare per year, a 26-percent reduction from the 20 grams per hectare for the no-practice scenario (table 20).

However, the total quantity of pesticide residues lost from the field is not the most useful outcome measure for assessing the environmental benefits of conservation practices. The environmental impact is specific to the toxicity of each pesticide to non-target species that may be exposed to the pesticide.

Pesticide risk indicators were therefore developed to represent risk at the edge-of-the field (bottom of soil profile for groundwater). These edge-of-field risk indicators are based on the ratio of pesticide concentrations in water leaving the field to safe concentrations (toxicity thresholds) for each pesticide. As such, these risk indicators do not have units. The pesticide risk indicators were developed so that the relative risk for individual pesticides could be aggregated over the 130 pesticides in use on cropped acres in the Chesapeake Bay region.[17]

Risk indicator values of less than 1 are considered “safe” because the concentration is below the toxicity threshold for exposure at the edge-of-the field.[18]

Three edge-of-field risk indicators are used here to assess the effects of conservation practices: (1) surface water pesticide risk indicator for aquatic ecosystems, (2) surface water pesticide risk indicator for humans, and (3) groundwater pesticide risk indicator for humans. The surface water risk indicator includes pesticide residues in solution in surface water runoff and in all subsurface water flow pathways that eventually return to surface water (water flow in a surface or tile drainage system, lateral subsurface water flow, and groundwater return flow). The pesticide risk indicator for aquatic ecosystems was based on chronic toxicities for fish and invertebrates, and acute toxicities for algae and vascular aquatic plants. The pesticide risk indicators for humans were based on drinking water standards or the equivalent for pesticides where standards have not been set.

These indicators provide a consistent measure that is comparable from field to field and that represents the effects of farming activities on risk reduction without being influenced by other landscape factors. In most environmental settings, however, non-target species are exposed to concentrations that have been diluted by water from other sources, even when those environments are located adjacent to a field. Consequently, these edge-of-field risk indicators cannot be used to predict actual environmental impacts.

Atrazine was the dominant pesticide contributing to all three risk indicators (table 22). Based on the model simulations, the edge-of-field risk indicator for atrazine exceeded 1 for 36 percent of the cropped acres for risk to aquatic ecosystems, 8 percent of the cropped acres for surface water risk to humans, and 7 percent of the cropped acres for groundwater risk to humans. Atrazine's dominance in the risk indicators is due to its widespread use, its mobility (solubility = 30 mg/L; Koc = 100 g/ml), its persistence (field half-life = 60 days), its toxicity to aquatic ecosystems (aquatic plant toxicity = 1 ppb), and the human drinking water standard (EPA Maximum Contaminant Level = 3 ppb).

The pesticide risk indicator for aquatic ecosystems averaged 1.76 over all years and cropped acres (table 20) for the baseline conservation condition. (The 1.76 value indicates that pesticide concentrations in water leaving cropped fields in the Chesapeake Bay region are, on average, 1.76 times the “safe” concentration for non-target plant and animal species.) The median value, however, is only 0.89 (fig. 49), indicating that the risk indicator for half of the acres is less than 0.89 and greater than 0.89 for half of the acres. Figure 48 shows that for most years the overall risk for aquatic ecosystems is low, in part because of the conservation practices in use. But in some years the edge-of-field concentrations can be high relative to "safe" thresholds for some acres.

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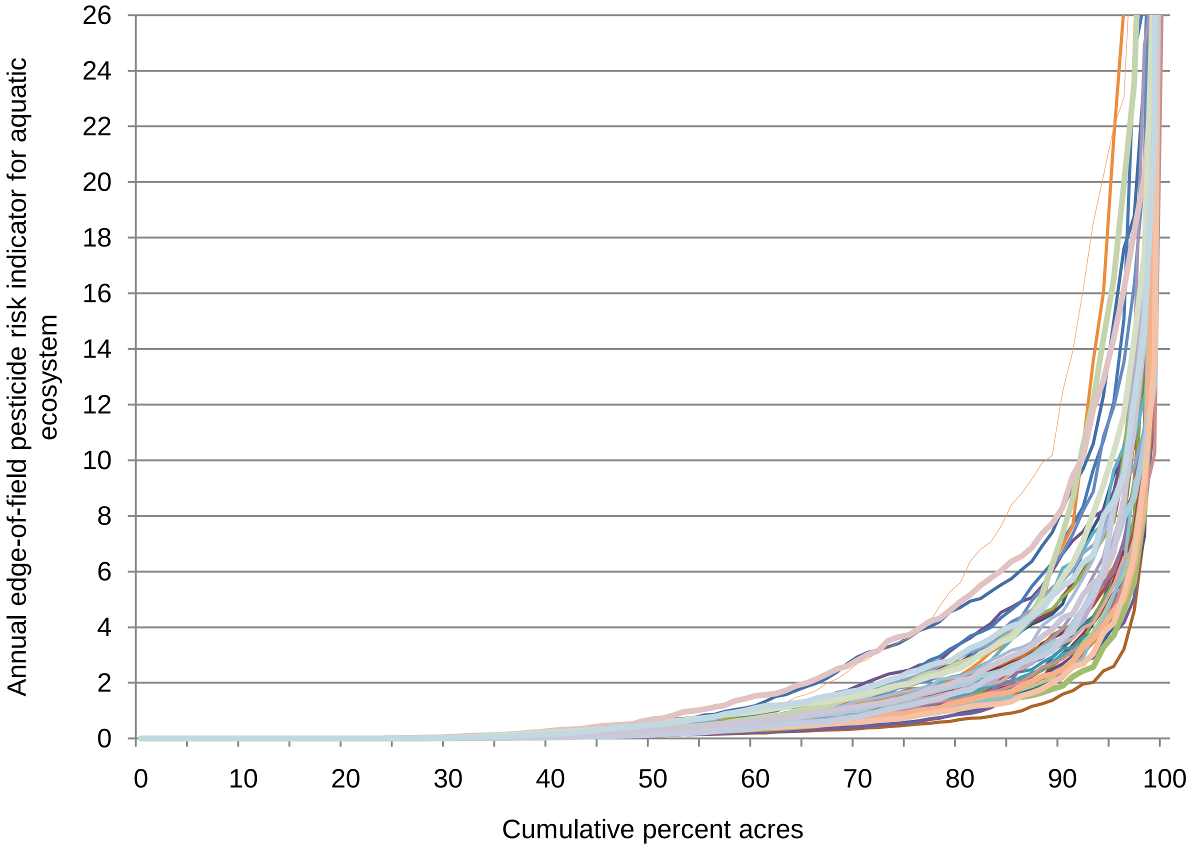
[17] For a complete documentation of the development of the pesticide risk indicators, see “Pesticide risk indicators used in the CEAP cropland modeling,” found at http://www.nrcs.usda.gov/technical/nri/ceap/cropland.html.

[18] A threshold value of 1 for the pesticide risk indicator applies when assessing the risk for a single pesticide. Since the indicator is summed over all pesticides in this study, a threshold value of 1 would still apply if pesticide toxicities are additive and no synergistic or antagonistic effects are produced when non-target species are exposed to a mix of pesticides.

Table 22. Dominant pesticides determining edge-of-field environmental risk, Chesapeake Bay region

Pesticide (active ingredient name)	Pesticide type	Percent of cropped acres in the region with average annual edge-of-field risk indicator greater than 1
Risk indicator for aquatic ecosystem		
Atrazine	Herbicide	36
Metolachlor	Herbicide	4
2,4-D 2-ethylhexyl ester	Herbicide	3
Sulfentrazone	Herbicide	2
Phostebupirim	Insecticide	<1
Linuron	Herbicide	<1
Risk indicator for humans, surface water		
Atrazine	Herbicide	8
Simazine	Herbicide	<1
Alachlor	Herbicide	<1
Dimethoate	Insecticide	<1
Terbofos	Insecticide	<1
Risk indicator for humans, groundwater		
Atrazine	Herbicide	7
Simazine	Herbicide	<1

Figure 48. Distribution of annual values of the edge-of-field surface water pesticide risk indicator for aquatic ecosystems for each year of the 47-year model simulation, Chesapeake Bay region



Note: This figure shows how the annual values of the risk indicator varied within the region and from year to year in the model simulation on cropped acres. Each of the 47 curves shown above represents a single year of data and shows how annual values of the risk indicator varied over the region in that year, starting with the acres with the lowest value and increasing to the acres with the highest value. The family of curves shows how annual values vary from year to year.

The pesticide risk indicators for humans were much lower, averaging 0.42 for surface water and 0.36 for groundwater (table 20). The median values are 0.17 for surface water and 0.08 for groundwater. Only about 11 percent of the cropped acres have an average annual edge-of-field surface water pesticide risk indicator for humans greater than 1 (fig. 50), and only 8 percent of the acres have an average annual bottom-of-the-rootzone groundwater pesticide risk indicator greater than 1.

The use of conservation practices in the Chesapeake Bay region has reduced the pesticide risk indicators by 30 to 34 percent (table 20), averaged over all years, all pesticides, and all cropped acres.

Figure 49. Estimates of average annual edge-of-field surface water pesticide risk indicator for aquatic ecosystem in the Chesapeake Bay region

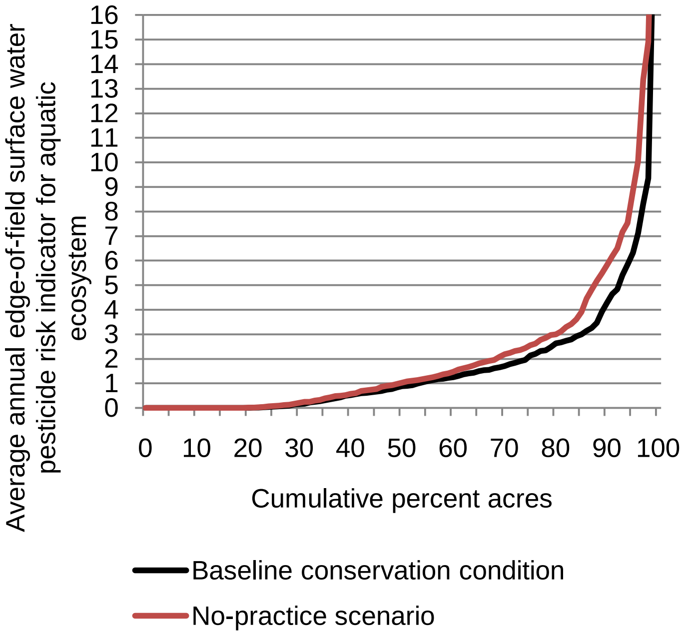


Figure 51 shows the distribution of the reductions in the two pesticide risk indicators due to conservation practices. Significant risk reductions for aquatic ecosystems occur on about 25 percent of the acres, while significant risk reductions for humans occur on only about 5 percent of the acres. The benefits of conservation practices were significant for both aquatic risks and human risks on the acres that had those risks, but aquatic risks were more widespread than human risks so conservation practices have greater total benefit for aquatic ecosystems than for human drinking water.

Figure 50. Estimates of average annual edge-of-field surface water pesticide risk indicator for humans in the Chesapeake Bay region

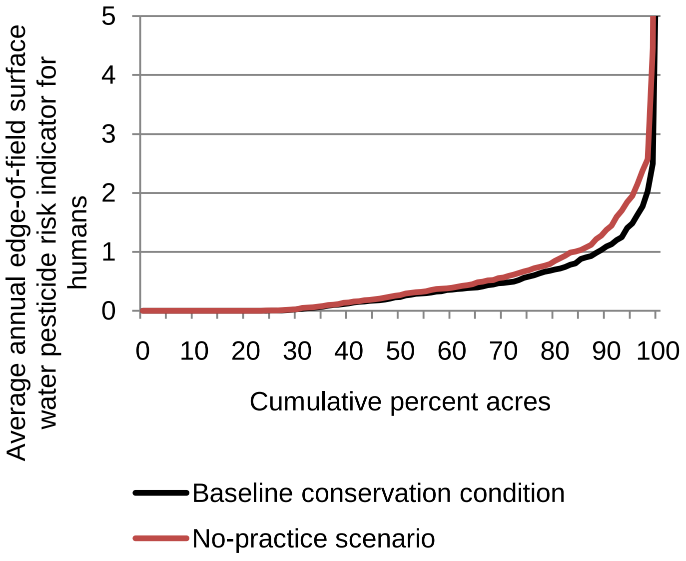
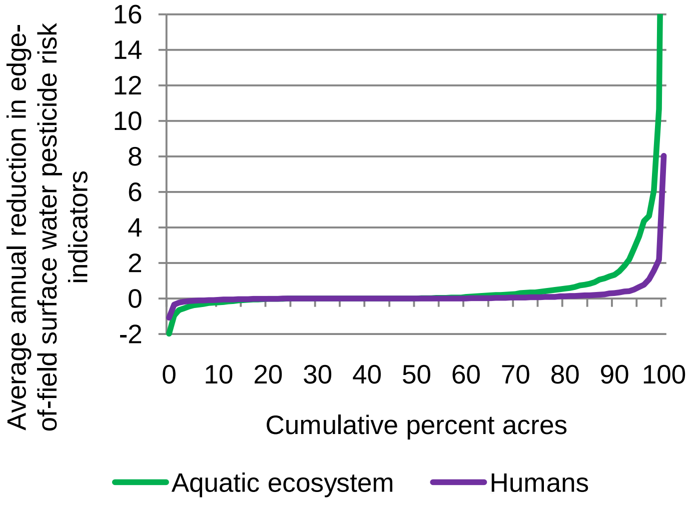


Figure 51. Estimates of average annual reductions in the edge-of-field surface water pesticide risk indicators for aquatic ecosystems in the Chesapeake Bay region



Note: Negative reductions in pesticide risk indicators result primarily from an increase in surface water runoff due to conservation practices (see figure 16).

Chapter 5
Assessment of Conservation Treatment Needs

The adequacy of conservation practices in use in the Chesapeake Bay region was evaluated to identify remaining conservation treatment needs for controlling sediment and nutrient loss from fields. The evaluation was based on conservation practice use for the time period 2003 through 2006.

In summary, findings for the Chesapeake Bay Region indicate that:

- *19 percent of cropped acres (810,000 acres) have a* ***high*** *level of need for additional conservation treatment,*
- *61 percent of cropped acres (2,598,000 acres) have a* ***moderate*** *level of need for additional conservation treatment, and*
- *20 percent of cropped acres (872,000 acres) have a* ***low*** *level of need for additional treatment and are considered to be adequately treated.*

Field-level model simulation results for the baseline conservation conditions were used to make the assessment. Four resource concerns were evaluated for the Chesapeake Bay region:

1. Sediment loss due to water erosion
2. Nitrogen loss with surface runoff (nitrogen attached to sediment and in solution)
3. Nitrogen loss in subsurface flows
4. Phosphorus lost to surface water (phosphorus attached to sediment and in solution, including soluble phosphorus in subsurface lateral flow pathways)

The conservation treatment needs for controlling pesticide loss were not evaluated because it requires information on pest infestations, which was not available for the CEAP sample points. A portion of the pesticide residues are controlled by soil erosion control practices; meeting soil erosion control treatment needs would provide partial protection against loss of pesticide residues from farm fields. Integrated Pest Management (IPM) practices are also effective in reducing the risk associated with pesticide residues leaving the farm field. Determination of adequate IPM, however, is highly dependent on the specific site conditions and the nature and extent of the pest problems.

Adequate conservation treatment consists of combinations of conservation practices that treat the specific inherent vulnerability factors associated with each field. Not all acres require the same level of conservation treatment. Acres with a high level of inherent vulnerability require more treatment than less vulnerable acres to reduce field-level losses to acceptable levels. Acres with characteristics such as steeper slopes and soil types that promote surface water runoff are more vulnerable to sediment and nutrient losses beyond the edge of the field. Acres that are essentially flat with porous soil types are more prone to nutrient losses through subsurface flow pathways, most of which return to surface water through drainage ditches, tile drains, natural seeps, and groundwater return flow.

Under-treated acres were identified by an imbalance between the level of conservation treatment and the level of inherent vulnerability.

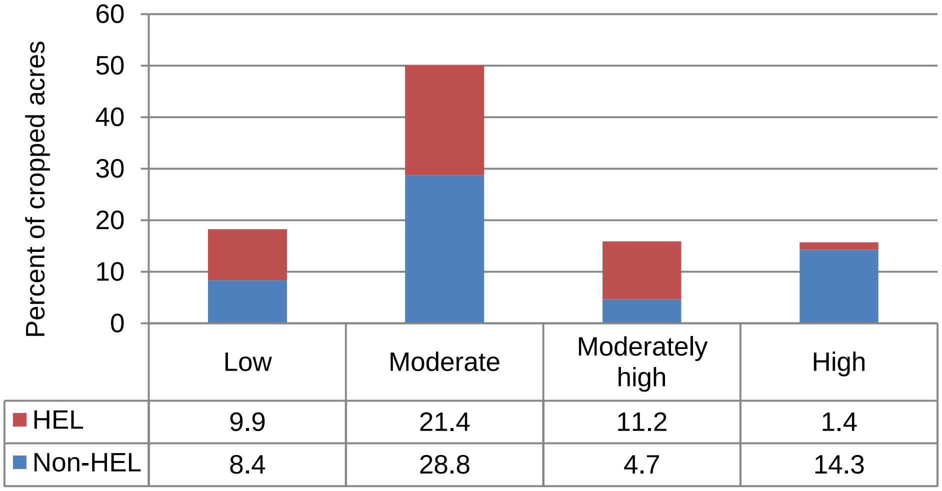
Conservation Treatment Levels

Four levels of conservation treatment (high, moderately high, moderate, and low) were defined. For sediment loss due to water erosion, conservation treatment levels were defined by a combination of structural practices and residue and tillage management practices, as defined in figure 52. For nitrogen loss with surface runoff, conservation treatment levels were defined by a combination of structural practices, residue and tillage management practices, and nitrogen management practices, as defined in figure 53. For phosphorus lost to surface water, conservation treatment levels were defined by a combination of structural practices, residue and tillage management practices, and phosphorus management practices, as defined in figure 54. The nitrogen management level presented in figure 9 (see chapter 3) was used to evaluate the adequacy of conservation treatment for nitrogen loss in subsurface flows.

A “high” level of treatment was shown by model simulations (see chapter 6) to reduce sediment and nutrient losses to low levels for nearly all cropped acres in the Chesapeake Bay region.

- A high level of water erosion control treatment is in use on about 16 percent of cropped acres (fig. 52), primarily on non-highly erodible land. Only 1 percent of cropped acres are highly erodible and have a high level of treatment. An additional 11 percent of the highly erodible acres have a moderately high level of water erosion control treatment.
- A high level of treatment for nitrogen runoff is in use on less than 1 percent of the acres (fig. 53). About 23 percent of the acres have combinations of practices that indicate a moderately high level of treatment.
- A high level of treatment for phosphorus runoff is in use on only 2 percent of the acres (fig. 54). About 22 percent of the acres have a moderately high level of treatment for controlling phosphorus loss with surface runoff.
- A high level of treatment for nitrogen loss in subsurface flows is in use on 11 percent of the acres (fig. 9). About 27 percent of the acres have a moderately high level of treatment for controlling nitrogen loss in subsurface flows.

Figure 52. Conservation treatment levels for water erosion control in the baseline conservation condition, Chesapeake Bay region



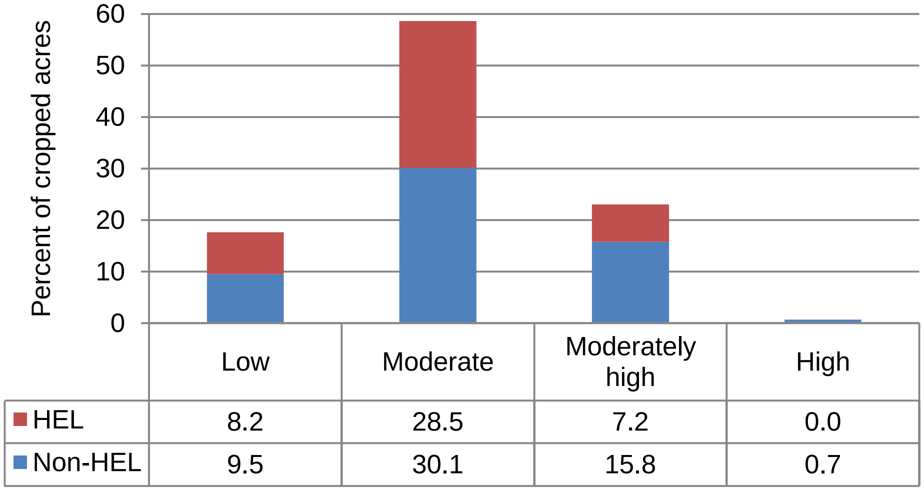
	Low	Moderate	Moderately high	High
🟥 HEL	9.9	21.4	11.2	1.4
🟦 Non-HEL	8.4	28.8	4.7	14.3

Criteria for water erosion control treatment levels were derived using a combination of structural practice treatment levels and residue and tillage management treatment levels (see figs. 7 and 8). Scores were first assigned to these treatment levels as follows: High=4, Moderately high=3, Moderate=2, and Low=1. If slope was 2 percent or less, the water erosion control treatment level is the same as the residue and tillage management level. If slope was greater than 2 percent, the water erosion control treatment level is determined as follows:

- **High treatment**: Sum of scores is equal to 8. (High treatment level for both structural practices and residue and tillage management practices).
- **Moderately high treatment**: Sum of scores equal to 6 or 7.
- **Moderate treatment**: Sum of scores equal to 4 or 5.
- **Low treatment**: Sum of scores equal to 2 or 3.

Note: About 44 percent of cropped acres in the Chesapeake Bay region is highly erodible land.

Figure 53. Conservation treatment levels for nitrogen runoff control in the baseline conservation condition, Chesapeake Bay region



	Low	Moderate	Moderately high	High
🟥 HEL	8.2	28.5	7.2	0.0
🟦 Non-HEL	9.5	30.1	15.8	0.7

Criteria were derived using a combination of structural practice treatment levels, residue and tillage management treatment levels, and nitrogen management treatment levels (see figs. 7-9). Scores were first assigned to these treatment levels as follows: High=4, Moderately high=3, Moderate=2, and Low=1.

If slope was 2 percent or less, the nitrogen runoff control treatment level is determined as follows:

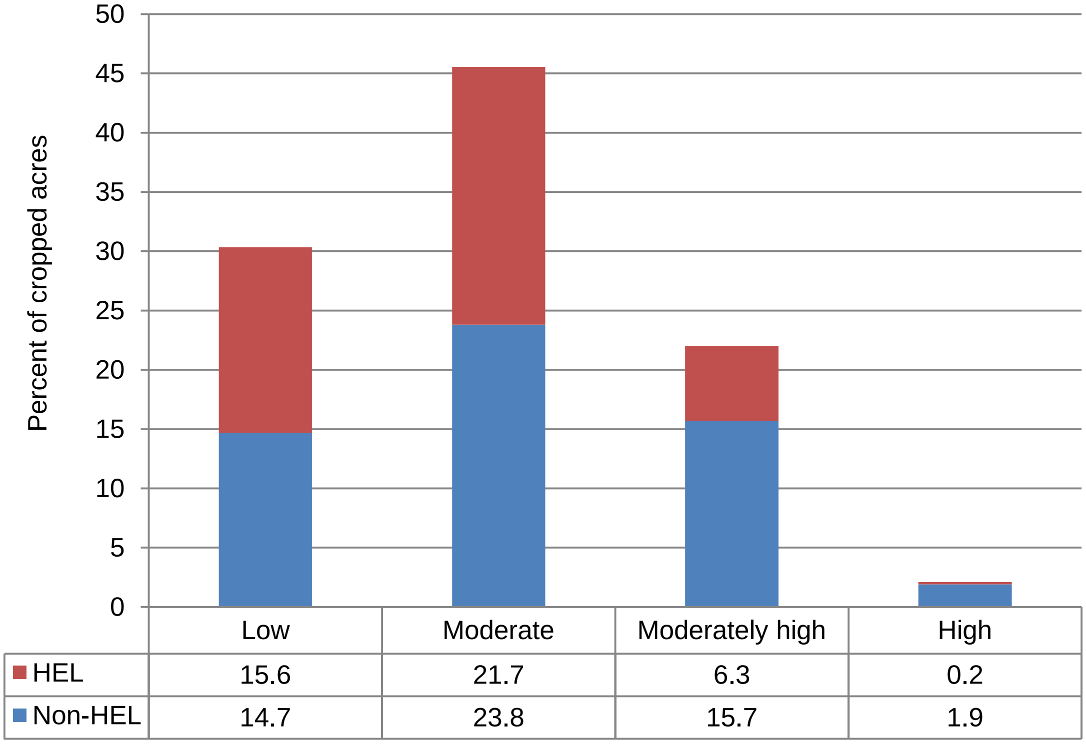
- **High treatment**: Sum of residue and tillage management score and nitrogen management score is equal to 8. (High treatment level for both structural practices and nitrogen management practices).
- **Moderately high treatment**: Sum of scores equal to 6 or 7.
- **Moderate treatment**: Sum of scores equal to 4 or 5.
- **Low treatment**: Sum of scores equal to 2 or 3.

If slope was greater than 2 percent, the nitrogen runoff control treatment level is determined as follows:

- **High treatment**: Sum of structural practice score, residue and tillage management score, and nitrogen management score is equal to 12. (High treatment level for all three treatment types.)
- **Moderately high treatment**: Sum of scores equal to 9, 10, or 11.
- **Moderate treatment**: Sum of scores equal to 6, 7 or 8.
- **Low treatment**: Sum of scores equal to 3, 4, or 5.

Note: About 44 percent of cropped acres in the Chesapeake Bay region is highly erodible land.

Figure 54. Conservation treatment levels for phosphorus runoff control in the baseline conservation condition, Chesapeake Bay region



	Low	Moderate	Moderately high	High
🟥 HEL	15.6	21.7	6.3	0.2
🟦 Non-HEL	14.7	23.8	15.7	1.9

Criteria were derived using a combination of structural practice treatment levels, residue and tillage management treatment levels, and phosphorus management treatment levels (see figs. 7, 8, and 10) in the same manner as the nitrogen runoff control treatment level. Scores were first assigned to these treatment levels as follows: High=4, Moderately high=3, Moderate=2, and Low=1.

If slope was 2 percent or less, the phosphorus runoff control treatment level is determined as follows:

- **High treatment**: Sum of residue and tillage management score and phosphorus management score is equal to 8. (High treatment level for both structural practices and phosphorus management practices).
- **Moderately high treatment**: Sum of scores equal to 6 or 7.
- **Moderate treatment**: Sum of scores equal to 4 or 5.
- **Low treatment**: Sum of scores equal to 2 or 3.

If slope was greater than 2 percent, the phosphorus runoff control treatment level is determined as follows:

- **High treatment**: Sum of structural practice score, residue and tillage management score, and phosphorus management score is equal to 12. (High treatment level for all three treatment types.)
- **Moderately high treatment**: Sum of scores equal to 9, 10, or 11.
- **Moderate treatment**: Sum of scores equal to 6, 7 or 8.
- **Low treatment**: Sum of scores equal to 3, 4, or 5.

Note: About 44 percent of cropped acres in the Chesapeake Bay region is highly erodible land.

Inherent Vulnerability Factors

Not all acres require the same level of conservation treatment because of differences in inherent vulnerabilities due to soils and climate. Inherent vulnerability factors for surface runoff include soil properties that promote surface water runoff and erosion—soil hydrologic group, slope, and K-factor. Inherent vulnerability factors for loss of nutrients in subsurface flows include soil properties that promote infiltration—soil hydrologic group, slope, K-factor, and coarse fragment content of the soil.

Soil runoff and leaching potentials were estimated for each sample point on the basis of vulnerability criteria. A single set of criteria was developed for all regions and soils in the US to allow for regional comparisons. Thus, some soil runoff and leaching potentials are not well represented in every region.

The criteria for the soil runoff potential are presented in figure 55, followed by the spatial distribution of the soil runoff potential within the Chesapeake Bay region in figure 56. The criteria and spatial distribution for the soil leaching potential are presented in figures 57 and 58.

The maps show the soil potentials for all soils and land uses in the region. For the assessment of conservation treatment needs, however, only the soil potentials for cropped acres were used.

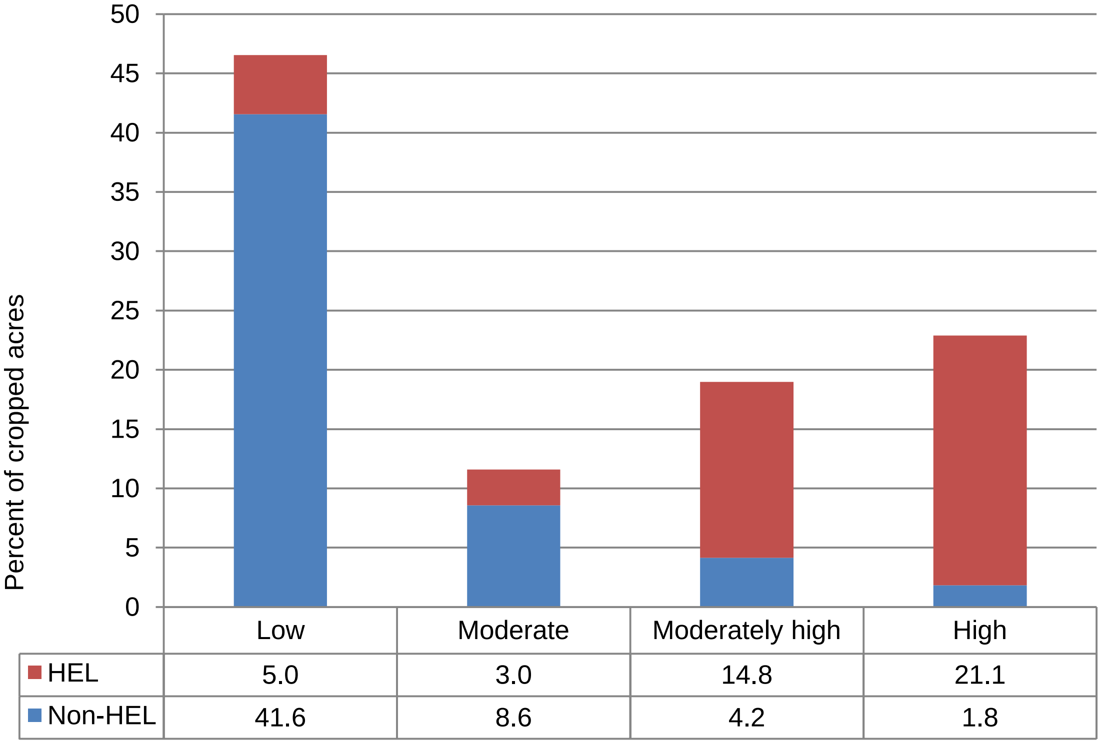
Cropped acres in the Chesapeake Bay region are a mix of vulnerable and non-vulnerable acres. About 47 percent of cropped acres in the Chesapeake Bay region have a low soil runoff potential (fig. 55). However, 23 percent of the acres have a high soil runoff potential, consisting almost entirely of highly erodible land, and 19 percent have a moderately high soil runoff potential.

About 17 percent of the cropped acres in the region have a high soil leaching potential (fig. 57). About 29 percent have a moderately high soil leaching potential and 48 percent have a moderate soil leaching potential. Only 6 percent of cropped acres have a low soil leaching potential in this region.

Estimates of sediment and nutrient losses for the no-practice scenario (without conservation practices) demonstrate how vulnerability factors influence losses in the Chesapeake Bay region.

- Sediment loss for the low soil runoff potential would have averaged 0.9 ton per acre per year without conservation practices, compared to 6.5 tons per acre per year for the high soil runoff potential.
- Nitrogen loss with surface runoff for the low soil runoff potential would have averaged 7 pounds per acre per year, compared to 32 pounds per acre per year for the high soil runoff potential.
- Nitrogen loss in subsurface flows for the low soil leaching potential would have averaged 29 pounds per acre per year, compared to 62 pounds per acre per year for the high soil leaching potential.
- Phosphorus lost to surface water for the low soil runoff potential would have averaged 4 pounds per acre per year, compared to 10 pounds per acre per year for the high soil runoff potential.

Figure 55. Soil runoff potential for cropped acres in the Chesapeake Bay region



Criteria for four classes of soil runoff potential were derived using a combination of soil hydrologic group, slope, and K-factor, as shown in the table below:

Soil runoff potential	Acres with soil hydrologic group A	Acres with soil hydrologic group B	Acres with soil hydrologic group C	Acres with soil hydrologic group D
Low	All acres	Slope<4	Slope<2	Slope<2 and K-factor<0.28
Moderate	None	Slope >=4 and <=6 and K-factor<0.32	Slope >=2 and <=6 and K-factor<0.28	Slope<2 and K-factor>=0.28
Moderately high	None	Slope >=4 and <=6 and K-factor>=0.32	Slope >=2 and <=6 and K-factor>=0.28	Slope >=2 and <=4
High	None	Slope>6	Slope>6	Slope>4

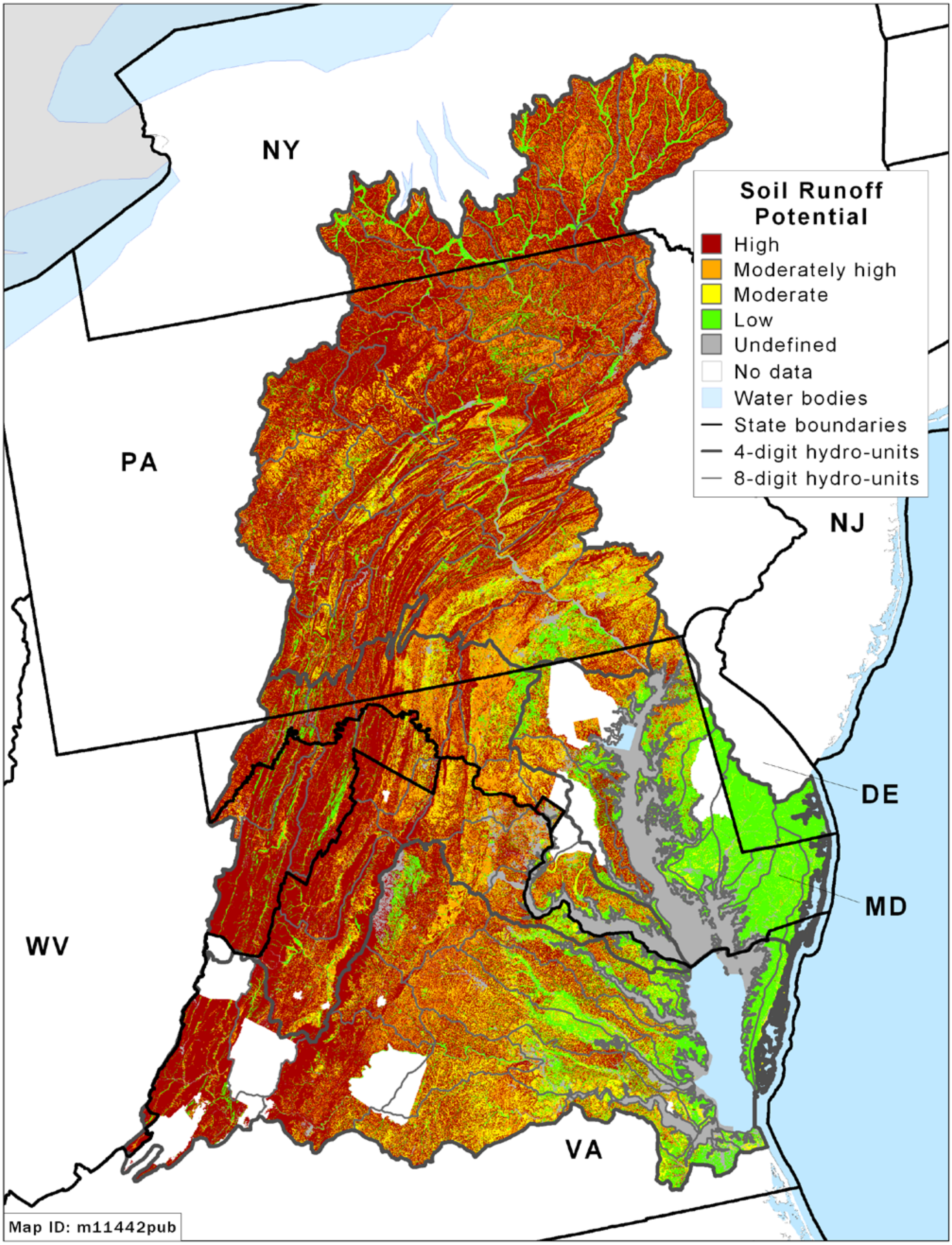
Hydrologic soil groups are classified as:

- **Group A**—sand, loamy sand, or sandy loam soils that have low runoff potential and high infiltration rates even when thoroughly wetted.
- **Group B**—silt loam or loam soils that have moderate infiltration rates when thoroughly wetted.
- **Group C**—sandy clay loam soils that have low infiltration rates when thoroughly wetted.
- **Group D**—clay loam, silty clay loam, sandy clay, silty clay, or clay soils that have very low infiltration rates when thoroughly wetted.

K-factor is a relative index of susceptibility of bare, cultivated soil to particle detachment and transport by rainfall. It is determined by the composition of the soil, saturated hydraulic conductivity, and soil structure.

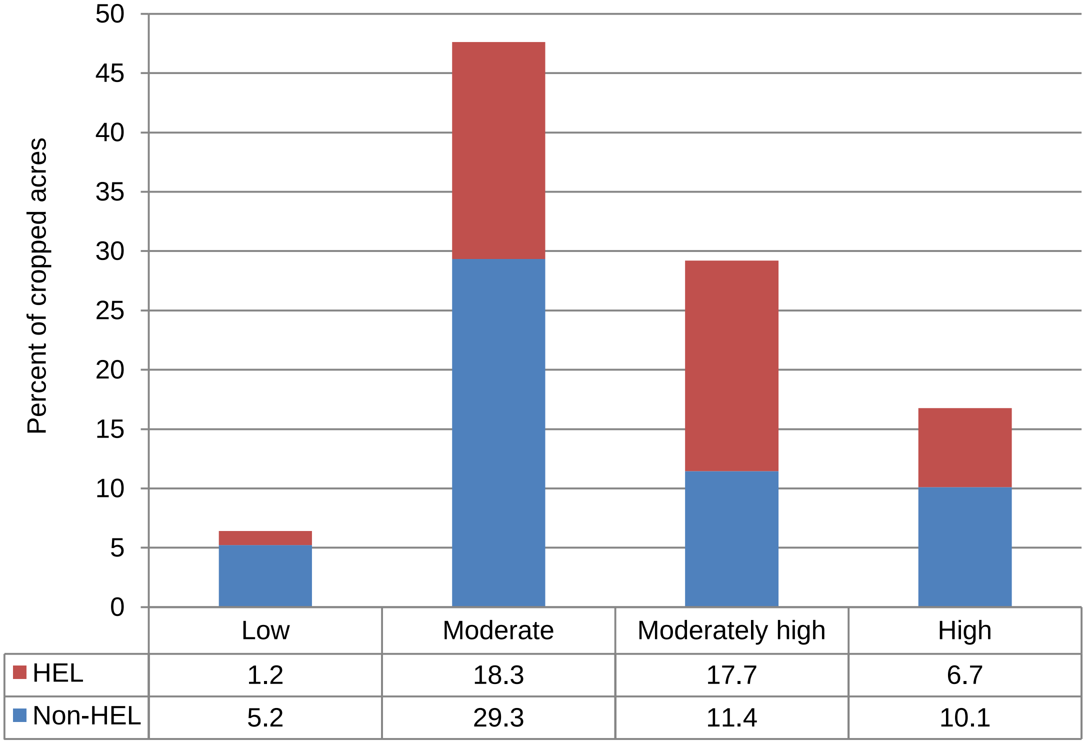
Note: About 44 percent of cropped acres in the Chesapeake Bay region is highly erodible land.

Figure 56. Soil runoff potential for soils in the Chesapeake Bay region



Note: The soil runoff potential shown in this map was derived using the criteria presented in figure 55 applied to soil characteristics for SSURGO polygons. All soils and land uses are represented.

Figure 57. Soil leaching potential for cropped acres in the Chesapeake Bay region



	Low	Moderate	Moderately high	High
🟥 HEL	1.2	18.3	17.7	6.7
🟦 Non-HEL	5.2	29.3	11.4	10.1

Criteria for four classes of soil leaching potential were derived using a combination of soil hydrologic group, slope, and K-factor, as shown in the table below:

Soil leaching potential	Acres with soil hydrologic group A	Acres with soil hydrologic group B	Acres with soil hydrologic group C	Acres with soil hydrologic group D
Low	None	None	None	All acres except organic soils
Moderate	None	Slope <=12 and K-factor>=0.24 or slope>12	All acres except organic soils	None
Moderately high	Slope>12	Slope >=3 and <=12 and K-factor<0.24	None	None
High	Slope<=12 or acres classified as organic soils	Slope<3 and K-factor <0.24 or acres classified as organic soils	Acres classified as organic soils	Acres classified as organic soils

Coarse fragments (stones and rocks) in the soil make it easier for water to infiltrate rather than run off. If the coarse fragment content of the soil was greater than 30 percent, the soil leaching potential was increased two levels (moderate and moderately high to high, and low to moderately high). If the coarse fragment content was greater than 10 percent but less than 30 percent, the soil leaching potential was increased one level.

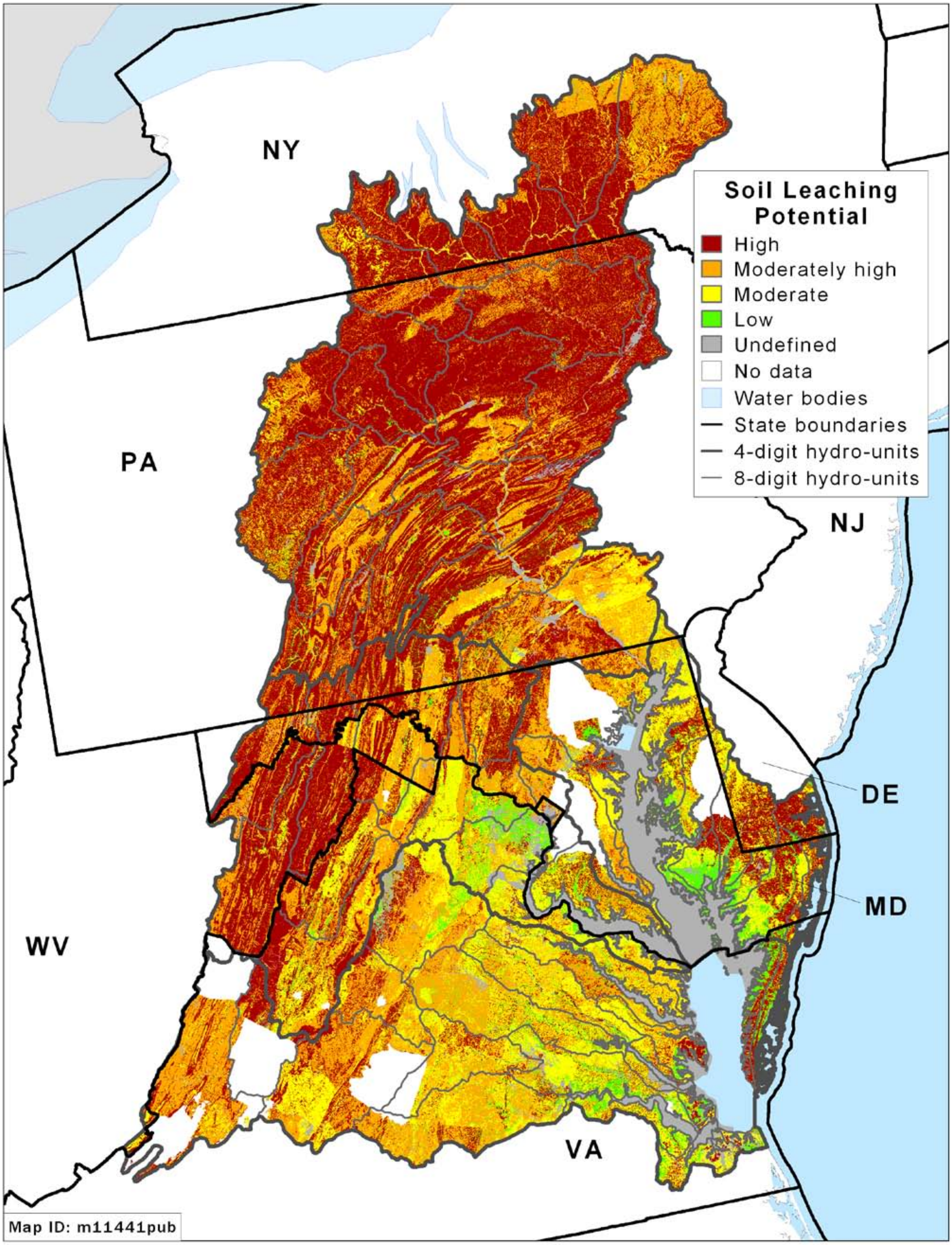
Hydrologic soil groups are classified as:

- **Group A—**sand, loamy sand, or sandy loam soils that have low runoff potential and high infiltration rates even when thoroughly wetted.
- **Group B**—silt loam or loam soils that have moderate infiltration rates when thoroughly wetted.
- **Group C**—sandy clay loam soils that have low infiltration rates when thoroughly wetted.
- **Group D**—clay loam, silty clay loam, sandy clay, silty clay, or clay soils that have very low infiltration rates when thoroughly wetted.

K-factor is a relative index of susceptibility of bare, cultivated soil to particle detachment and transport by rainfall. It is determined by the composition of the soil, saturated hydraulic conductivity, and soil structure.

Note: About 44 percent of cropped acres in the Chesapeake Bay region is highly erodible land.

Figure 58. Soil leaching potential for soils in the Chesapeake Bay region



Note: The soil leaching potential shown in this map was derived using the criteria presented in figure 57 applied to soil characteristics for SSURGO polygons. All soils and land uses are represented.

Evaluation of Conservation Treatment

The “matrix approach”

A “matrix approach” was used to identify acres where the level of conservation treatment was inadequate relative to the level of inherent vulnerability due to soils and climate. These acres are referred to as “under-treated acres.” Levels of conservation treatment in the baseline conservation condition were evaluated using both the levels of conservation treatment and the soil runoff/leaching potentials. Cropped acres were divided into 16 groups—four soil vulnerability potentials and four treatment levels.

The high or moderately high treatment levels are effective in reducing losses for all soil potentials, as shown in figures 59 through 62.

The matrixes are presented in tables 23 through 26. Acres and model results for each of the 16 groupings are presented in the first five matrixes in each table. This matrix approach was very effective in segregating acres with high losses from acres with low losses.

- Estimates of sediment and nutrient loss for the no-practice scenario consistently increased from small losses for the low soil runoff or leaching potential to large losses for the high soil runoff or leaching potential. As the no-practice scenario represents crop production without conservation practices, there is no consistent relationship in loss estimates among the four conservation treatment levels. The differences in losses among conservation treatment levels reflect the underlying variability, which is also influenced by the number of acres in each group.

Figure 59. Trend in average annual sediment loss for increasing levels of soil runoff potential at two levels of conservation treatment, Chesapeake Bay Region

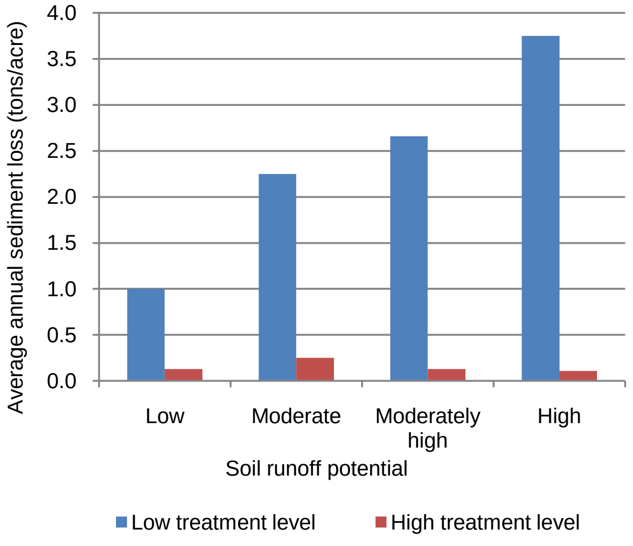
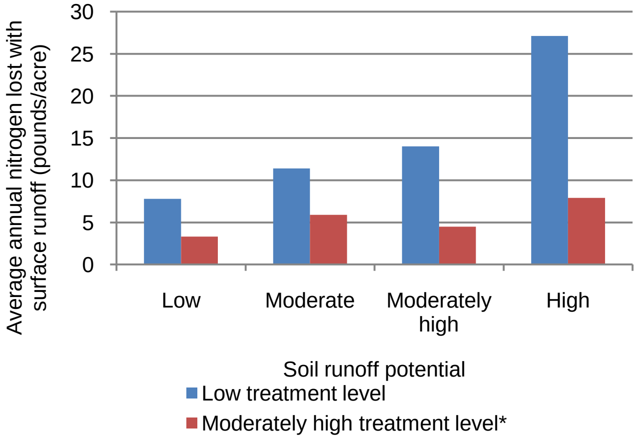


Figure 60. Trend in average annual nitrogen loss with surface runoff for increasing levels of soil runoff potential at two levels of conservation treatment, Chesapeake Bay Region



* There was not sufficient sample size to report values for the high treatment class.

Figure 61. Trend in average annual nitrogen loss in subsurface flows for increasing levels of soil leaching potential at two levels of conservation treatment, Chesapeake Bay Region

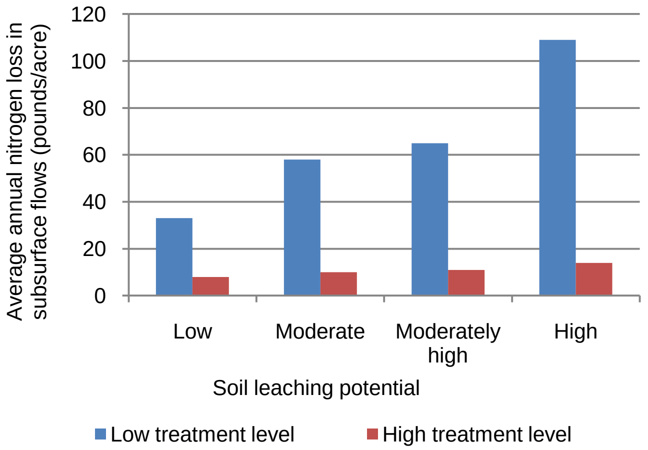
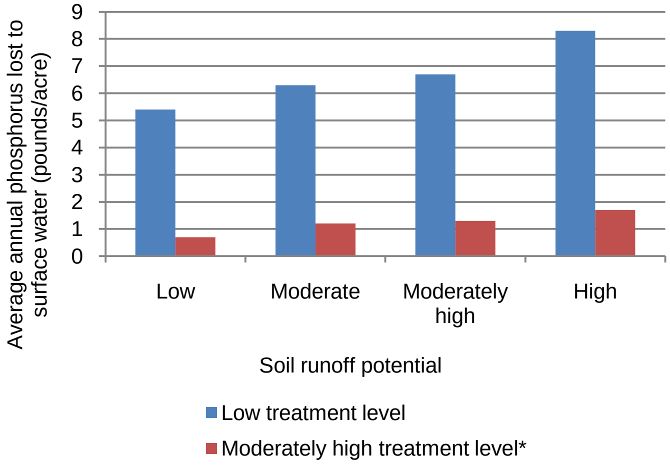


Figure 62. Trend in average annual phosphorus lost to surface water for increasing levels of soil runoff potential at two levels of conservation treatment, Chesapeake Bay Region



* There was not sufficient sample size to report values for the high treatment class.

- Estimates of sediment and nutrient loss for the baseline conservation condition exhibit a nearly consistent trend of decreasing loss with increasing treatment level within each soil runoff or leaching potential.
- The highest losses in the baseline conservation condition were for groups of acres where the conservation treatment level was one step or more below the soil leaching or runoff potential.

The evaluation of conservation treatment needs was conducted by identifying which of the 16 groups of acres are inadequately treated with respect to the soil runoff or soil leaching potential. Three levels of conservation treatment need were identified.

- Acres with a “high” level of need for conservation treatment consist of the most critical under-treated acres in the region. These are the most vulnerable of the under-treated acres with the least conservation treatment and have the highest losses of sediment and/or nutrients.
- Acres with a “moderate” level of need for conservation treatment consist of under-treated acres that generally have lower levels of vulnerability and/or have more conservation practice use than acres with a high level of need. The treatment level required is not necessarily less, although it can be, but rather the sediment and nutrient losses are lower and thus there is less potential on a per-acre basis for reducing agricultural pollutant loadings with additional conservation treatment.
- Acres with a “low” level of need for conservation treatment consist of acres that are adequately treated with respect to the level of inherent vulnerability. While gains can be obtained by adding conservation practices to some of these acres, additional conservation treatment would reduce field losses by only a small amount.

The last two matrixes in each of the tables 23 through 26 shows how conservation treatment needs were identified. Specific criteria were used to identify the groups of acres that fall into each of the three levels of conservation treatment need. Criteria were not tailored to a specific region, but were derived for use in all regions of the country to allow for comparisons of under-treated acres across regions using a consistent analytical framework. The criteria and steps in the process are as follows.

1. The percentage of acres that exceeded a given level of loss was estimated for each cell in the matrix as a guide to determining the extent of excessive losses, shown in tables 23 through 26. These are referred to as “acceptable levels.” *Losses above these levels were treated as unacceptable levels of loss.* “Acceptable levels” for field-level losses used in this study are—
    - Average of 2 tons per acre per year for sediment loss
    - Average of 15 pounds per acre per year for nitrogen loss with surface runoff (soluble and sediment attached)
    - Average of 25 pounds per acre per year for nitrogen loss in subsurface flows
    - Average of 4 pounds per acre per year for phosphorus lost to surface water (soluble and sediment attached)
2. Groups of acres with less than 30 percent of the acres exceeding acceptable levels were defined as adequately treated acres and designated as having a **low level of conservation treatment need**.
3. Groups of acres with more than 60 percent of the acres in excess of acceptable levels were designated as having a **high level of conservation treatment need,** indicated by darker shaded cells in the matrixes.
4. The remaining acres were designated as having a **moderate level of conservation treatment need**, indicated by lighter shaded cells in the matrix.

Under-treated acres—those groups of acres with either a high or moderate level of conservation treatment need—are shown in the last matrix in each table. In most cases, under-treated acres consisted of acres where the conservation treatment level was one step or more below the soil leaching or runoff potential (indicated by the red boundary shown in the baseline conservation condition matrix).

Acceptable levels were initially derived through a series of forums held at professional meetings of researchers working on fate and transport of sediment and nutrients in agriculture. Those meetings produced a range of estimates for edge-of-field sediment loss, nitrogen loss, and phosphorus loss, representing what could be realistically achieved with today’s production and conservation technologies. The range was narrowed by further examination of APEX model output, which also showed that the levels selected were agronomically feasible in all agricultural regions of the country. In the Chesapeake Bay region, for example, percentages of acres that can attain these acceptable levels with additional soil erosion control and nutrient management practices on all under-treated acres are (see the next chapter):

- 99 percent of cropped acres for sediment loss,
- 99 percent of cropped acres for nitrogen loss with surface runoff,
- 88 percent of cropped acres for nitrogen loss in subsurface flows, and
- 91 percent of cropped acres for phosphorus lost to surface water.

The criteria used to identify acres that need additional treatment, including acceptable levels, are not intended to provide adequate protection of water quality, although for some environmental settings they may be suitable for that purpose. Evaluation of how much additional conservation treatment is needed to meet Federal, State, and/or local water quality goals in the region is beyond the scope of this study.

Table 23. Identification of under-treated acres for sediment loss due to water erosion in the Chesapeake Bay region

	Conservation treatment levels for water erosion control				
Soil runoff potential	Low	Moderate	Moderately high	High	All
Estimated cropped acres					
Low	238,374	958,787	230,998	564,256	1,992,414
Moderate	153,509	242,434	65,585	34,493	496,021
Moderately high	186,902	447,148	131,542	46,549	812,140
High	202,678	497,055	252,723	26,869	979,325
All	781,462	2,145,424	680,848	672,167	4,279,900
Percent of cropped acres					
Low	6	22	5	13	47
Moderate	4	6	2	1	12
Moderately high	4	10	3	1	19
High	5	12	6	1	23
All	18	50	16	16	100
Sediment loss estimates *without* conservation practices (no-practice scenario, average annual tons/acre)					
Low	1.39	0.85	1.10	0.54	0.85
Moderate	2.98	1.86	3.01	0.60	2.27
Moderately high	3.57	2.23	2.88	1.57	2.61
High	5.79	7.22	5.72	4.90	6.48
All	3.37	2.73	3.34	0.79	2.64
Sediment loss estimates for the baseline conservation condition (average annual tons/acre)					
Low	1.00	0.43	0.19	0.13	0.38
Moderate	2.25	0.72	0.54	0.25	1.14
Moderately high	2.66	1.03	0.55	0.13	1.27
High	3.75	3.40	0.93	0.11	2.75
All	2.36	1.27	0.57	0.14	1.18
Percent reduction in sediment loss due to conservation practices					
Low	28	50	83	75	55
Moderate	25	61	82	58	50
Moderately high	26	54	81	92	51
High	35	53	84	98	58
All	30	53	83	82	55
Percent of acres in baseline conservation condition with average annual sediment loss more than 2 tons/acre					
Low	4	6	0	0	3
Moderate	48	6	0	0	18
Moderately high	42	13	4	0	18
High	64	54	2	0	41
All	37	18	2	0	16
Estimate of under-treated acres					
Low	0	0	0	0	0
Moderate	153,509	0	0	0	153,509
Moderately high	186,902	0	0	0	186,902
High	202,678	497,055	0	0	699,733
All	543,088	497,055	0	0	1,040,143

Note: Cells below the red boundary shown for the baseline conservation condition are the acres where the level of conservation treatment is one step or more below the soil runoff potential. These cells consistently had the highest losses in the model simulations.

Note: Color-shaded cells indicate under-treated acres; groups of acres with more than 30 percent of the acres exceeding acceptable levels were defined as under-treated acres. Darker color-shaded cells indicate critical under-treated acres; critical under-treated acres were defined as groups of acres with more than 60 percent of the acres in excess of acceptable levels.

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Percents may not add to totals because of rounding.

Table 24. Identification of under-treated acres for nitrogen loss with surface runoff (sediment attached and soluble) in the Chesapeake Bay region

	Conservation treatment levels for nitrogen runoff control				
Soil runoff potential	Low	Moderate	Moderately high	High	All
Estimated cropped acres					
Low	302,053	1,028,547	631,632	30,182	1,992,414
Moderate	147,417	260,991	87,613	0	496,021
Moderately high	147,863	513,303	150,974	0	812,140
High	158,399	705,199	115,727	0	979,325
All	755,732	2,508,040	985,946	30,182	4,279,900
Percent of cropped acres					
Low	7	24	15	<1	47
Moderate	3	6	2	0	12
Moderately high	3	12	4	0	19
High	4	16	3	0	23
All	18	59	23	<1	100
Estimates of nitrogen loss with surface runoff *without* conservation practices (no-practice scenario, average annual pounds/acre)					
Low	11.8	6.6	6.7	3.3	7.4
Moderate	17.6	11.9	12.0	NA	13.6
Moderately high	18.9	15.3	12.1	NA	15.4
High	41.9	30.6	22.9	NA	31.5
All	20.6	15.7	9.9	3.3	15.1
Estimates of nitrogen loss with surface runoff for the baseline conservation condition (average annual pounds/acre)					
Low	7.8	3.6	3.3	2.0	4.1
Moderate	11.4	6.4	5.9	NA	7.8
Moderately high	14.0	9.6	4.5	NA	9.5
High	27.1	18.1	7.9	NA	18.3
All	13.8	9.2	4.3	2.0	8.8
Percent reduction in nitrogen loss with surface runoff due to conservation practices					
Low	34	46	50	39	44
Moderate	35	46	51	NA	43
Moderately high	26	37	62	NA	38
High	35	41	66	NA	42
All	33	41	57	39	42
Percent of acres in baseline conservation condition with average annual nitrogen loss with surface runoff more than 15 pounds/acre					
Low	12	2	0	0	3
Moderate	28	4	0	NA	10
Moderately high	35	19	0	NA	18
High	73	50	11	NA	49
All	32	19	1	0	17
Estimate of under-treated acres for nitrogen loss with surface runoff					
Low	0	0	0	0	0
Moderate	0	0	0	0	0
Moderately high	147,863	0	0	0	147,863
High	158,399	705,199	0	0	863,598
All	480,466	705,199	0	0	1,011,461

Note: Cells below the red boundary shown for the baseline conservation condition are the acres where the level of conservation treatment is one step or more below the soil runoff potential. These cells consistently had the highest losses in the model simulations.

Note: Color-shaded cells indicate under-treated acres; groups of acres with more than 30 percent of the acres exceeding acceptable levels were defined as under-treated acres. Darker color-shaded cells indicate critical under-treated acres; critical under-treated acres were defined as groups of acres with more than 60 percent of the acres in excess of acceptable levels.

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Percents may not add to totals because of rounding.

Note: NA indicates not applicable because there were no acres in the category.

Table 25. Identification of under-treated acres for nitrogen loss in subsurface flows in the Chesapeake Bay region

	Conservation treatment levels for nitrogen management				
Soil leaching potential	Low	Moderate	Moderately high	High	All
Estimated cropped acres					
Low	63,413	94,946	75,796	40,884	275,040
Moderate	466,151	836,068	533,735	202,304	2,038,260
Moderately high	277,231	450,068	408,474	113,392	1,249,166
High	147,787	317,466	149,428	102,753	717,434
All	954,583	1,698,549	1,167,435	459,334	4,279,900
Percent of cropped acres					
Low	1	2	2	1	6
Moderate	11	20	12	5	48
Moderately high	6	11	10	3	29
High	3	7	3	2	17
All	22	40	27	11	100
Estimates of nitrogen loss in subsurface flows *without* conservation practices (no-practice scenario, average annual pounds/acre)					
Low	48	32	15	18	29
Moderate	72	40	26	25	42
Moderately high	89	47	38	27	51
High	128	54	39	24	62
All	84	44	31	25	47
Estimates of nitrogen loss in subsurface flows for the baseline conservation condition (average annual pounds/acre)					
Low	33	28	8	8	21
Moderate	58	31	10	10	30
Moderately high	65	36	12	11	32
High	109	42	17	14	47
All	67	34	11	11	33
Percent reduction in nitrogen loss in subsurface flows due to conservation practices					
Low	31	13	49	54	29
Moderate	19	22	63	61	30
Moderately high	27	22	69	60	37
High	15	21	57	44	24
All	21	21	64	56	31
Percent of acres in baseline conservation condition with average annual nitrogen loss in subsurface flows more than 25 pounds/acre					
Low	41	41	6	0	25
Moderate	53	39	6	4	30
Moderately high	66	54	6	3	36
High	89	59	23	6	50
All	61	47	8	4	35
Estimate of under-treated acres for nitrogen loss in subsurface flows					
Low	63,413	94,946	0	0	158,359
Moderate	466,151	836,068	0	0	1,302,220
Moderately high	277,231	450,068	0	0	727,300
High	147,787	317,466	0	0	465,254
All	954,583	1,698,549	0	0	2,653,132

Note: Cells below the red boundary shown for the baseline conservation condition are the acres where the level of conservation treatment is one step or more below the soil leaching potential. These cells consistently had the highest losses in the model simulations.

Note: Color-shaded cells indicate under-treated acres; groups of acres with more than 30 percent of the acres exceeding acceptable levels were defined as under-treated acres. Darker color-shaded cells indicate critical under-treated acres; critical under-treated acres were defined as groups of acres with more than 60 percent of the acres in excess of acceptable levels.

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Percents may not add to totals because of rounding.

Table 26. Identification of under-treated acres for phosphorus lost to surface water (phosphorus attached to sediment and in solution, including soluble phosphorus in subsurface lateral flow pathways) in the Chesapeake Bay region

	Conservation treatment levels for phosphorus runoff control				
Soil runoff potential	Low	Moderate	Moderately high	High	All
Estimated cropped acres					
Low	433,234	842,870	636,510	79,799	1,992,414
Moderate	208,900	228,271	58,850	*	496,021
Moderately high	270,049	411,749	120,304	*	812,140
High	386,555	465,724	127,045	*	979,325
All	1,298,738	1,948,614	942,710	89,838	4,279,900
Percent of cropped acres					
Low	10	20	15	2	47
Moderate	5	5	1	*	12
Moderately high	6	10	3	*	19
High	9	11	3	*	23
All	30	46	22	2	100
Phosphorus lost to surface water *without* conservation practices (no-practice scenario, average annual pounds/acre)					
Low	6.7	3.0	3.5	4.7	4.0
Moderate	8.3	5.1	5.9	*	6.5
Moderately high	8.1	6.6	6.0	*	7.0
High	11.6	9.0	6.2	*	9.7
All	8.7	5.4	4.3	4.9	6.2
Phosphorus lost to surface water for the baseline conservation condition (average annual pounds/acre)					
Low	5.4	1.8	0.7	0.6	2.2
Moderate	6.3	2.7	1.2	*	4.0
Moderately high	6.7	3.9	1.3	*	4.4
High	8.3	5.0	1.7	*	5.8
All	6.7	3.1	1.0	0.7	3.7
Percent reduction in phosphorus lost to surface water due to conservation practices					
Low	19	38	79	87	45
Moderate	24	47	79	*	38
Moderately high	18	41	79	*	37
High	29	45	72	*	40
All	24	43	78	87	41
Percent of acres in baseline conservation condition with average annual phosphorus lost to surface water more than 4 pounds/acre					
Low	43	14	0	0	15
Moderate	56	23	0	*	34
Moderately high	56	32	4	*	35
High	78	42	9	*	52
All	58	26	2	0	30
Estimate of under-treated acres for phosphorus lost to surface water					
Low	433,234	0	0	0	433,234
Moderate	208,900	0	0	0	208,900
Moderately high	270,049	411,749	0	0	681,798
High	386,555	465,724	0	0	852,280
All	1,298,738	877,473	0	0	2,176,211

Note: Cells below the red boundary shown for the baseline conservation condition are the acres where the level of conservation treatment is one step or more below the soil runoff potential. These cells consistently had the highest losses in the model simulations.

Note: Color-shaded cells indicate under-treated acres; groups of acres with more than 30 percent of the acres exceeding acceptable levels were defined as under-treated acres. Darker color-shaded cells indicate critical under-treated acres; critical under-treated acres were defined as groups of acres with more than 60 percent of the acres in excess of acceptable levels.

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Percents may not add to totals because of rounding.

* Estimate not reported because there were only 4 or fewer sample points available in the category.

Conservation treatment needs by resource concern

The proportion of cropped acres with a high or moderate need for additional conservation treatment was determined to be (fig. 63)—

- 24 percent for sediment loss (5 percent with a high need for treatment),
- 24 percent for nitrogen loss with runoff (4 percent with a high need for treatment),
- 51 percent for phosphorus lost to surface water (9 percent with a high need for treatment), and
- 62 percent for nitrogen loss in subsurface flows (10 percent with a high need for treatment), most of which returns to surface water through drainage ditches, tile drains, natural seeps, and groundwater return flow.

Under-treated acres in the Chesapeake Bay region are presented by combinations of resource concerns in table 27. About 36 percent of cropped acres are under-treated for only one of the four resource concerns, usually nitrogen leaching:

- 28 percent of cropped acres are under-treated only for nitrogen leaching,
- 8 percent of cropped acres are under-treated only for phosphorus runoff, and
- less than 1 percent of cropped acres are under-treated only for sediment loss.

Nitrogen runoff and phosphorus runoff was the most frequently occurring combination of resource concerns, representing 15 percent cropped acres. About 12 percent of cropped acres were determined to be under-treated for all four resource concerns.

The most critical conservation concern in the region is the need for complete and consistent use of nutrient management—appropriate rate, form, timing, *and* method of application. While most cropped acres have some nutrient management practices in use, 18 percent have a high need for additional treatment to better control nitrogen and/or phosphorus loss from fields. About 79 percent have a high or moderate need for additional nutrient management for nitrogen and/or phosphorus (table 27).

Figure 63. Percent of cropped acres that are under-treated in the Chesapeake Bay Region, by resource concern

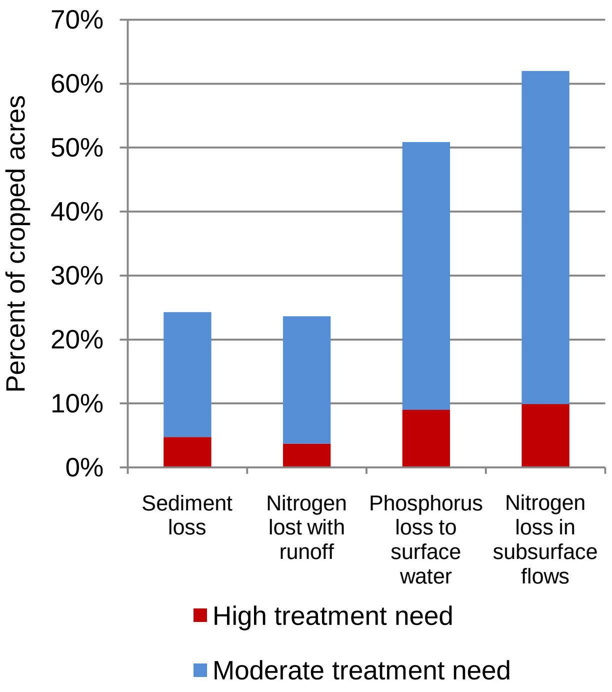


Table 27. Under-treated acres with resource concerns needing treatment in the Chesapeake Bay region

Reason for treatment need	Estimated acres needing treatment	Percent of cropped acres	Percent of under-treated acres
Nitrogen leaching only	1,178,363	27.5	34.6
Nitrogen and phosphorus runoff	649,438	15.2	19.1
Sediment, nitrogen and phosphorus runoff, and nitrogen leaching	521,727	12.2	15.3
Phosphorus runoff only	347,165	8.1	10.2
Sediment, nitrogen runoff and phosphorus runoff	288,472	6.7	8.5
Nitrogen leaching, nitrogen runoff, and phosphorus runoff	164,796	3.9	4.8
Sediment, phosphorus runoff, and nitrogen leaching	108,342	2.5	3.2
Sediment and phosphorus runoff	96,271	2.2	2.8
Nitrogen leaching and nitrogen runoff	28,019	0.7	0.8
Sediment only	14,438	0.3	0.4
Sediment and nitrogen runoff	8,446	0.2	0.2
Sediment and nitrogen leaching	2,447	0.1	0.1
All under-treated acres	3,407,924	79.6	100.0

Note: This table summarizes the under-treated acres identified in tables 37-40 and reports the joint set of acres that need treatment according to combinations of resource concerns.

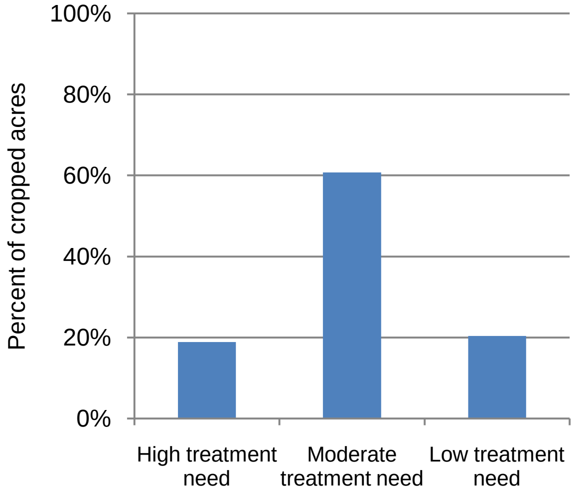
Note: Percents may not add to totals because of rounding.

Conservation treatment needs for one or more resource concern

Some acres require additional treatment for only one of the four resource concerns, while other acres require additional treatment for two or more resource concerns. After accounting for acres that need treatment for multiple resource concerns, the evaluation of treatment needs for the Chesapeake Bay region determined the following (fig. 64 and table 28):

- 19 percent of cropped acres (810,000 acres) have a **high** level of need for additional conservation treatment.
- 61 percent of cropped acres (2,598,000 acres) have a **moderate** level of need for additional conservation treatment.
- 20 percent of cropped acres (872,000 acres) have a **low** level of need for additional treatment and are considered to be adequately treated.

Figure 64. Percent of cropped acres with a high, moderate, or low level of need for additional conservation treatment for one or more resource concern in the Chesapeake Bay Region



High level of need for conservation treatment. Acres with a “high” level of need for conservation treatment consist of the most critical under-treated acres in the region (table 28 and figs. 65 through 68). These are the most vulnerable of the under-treated acres with the least conservation treatment and have the highest losses of sediment and/or nutrients. Eighty-seven percent of these acres have losses higher than the acceptable level criteria used in the matrix approach for either sediment or nutrients. These acres lose (per acre per year, on average)—

- 2.5 tons of sediment,
- 7.6 pounds of phosphorus,
- 16 pounds of nitrogen with surface runoff, and
- 60 pounds of nitrogen in subsurface flows.

Acres with a high level of treatment need have the greatest potential for reducing agricultural pollutant loadings with additional conservation treatment.

Moderate level of need for conservation treatment. Acres with a “moderate” level of need for conservation treatment consist of under-treated acres that generally have lower levels of vulnerability and/or have more conservation practice use than acres with a high level of need (table 28 and figs. 65 through 68).The sediment and nutrient losses are lower than those with a high need for additional treatment and thus there is less potential on a per-acre basis for reducing agricultural pollutant loadings with additional conservation treatment. Fifty-five percent of these acres have losses higher than the acceptable level criteria used in the matrix approach for either sediment or nutrients. These acres lose (per acre per year, on average)—

- 1.0 ton of sediment,
- 3.5 pounds of phosphorus,
- 8 pounds of nitrogen with surface runoff, and
- 32 pounds of nitrogen in subsurface flows.

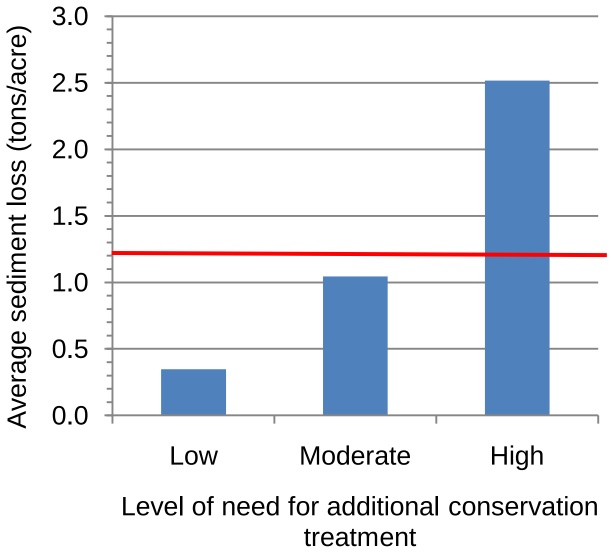
While the benefit of additional treatment of acres with a moderate level of treatment need is less than for acres with a high level of treatment need, a portion of these acres may need to be treated to meet water quality goals in the region. For example, it may be that some of the acres with a moderate treatment need for nitrogen loss will need additional treatment to meet goals for reducing nitrogen loads to the Bay. (Evaluation of conservation treatment needed to meet water quality goals in the region is beyond the scope of this study.)

Low level of need for conservation treatment. Acres with a low level of need for conservation treatment consist of acres that are adequately treated with respect to the level of inherent vulnerability (table 28 and figs. 65 through 68). Only 7 percent of these acres have losses higher than the acceptable level criteria used in the matrix approach, almost all of which are for a single resource concern. These acres lose (per acre per year, on average)—

- 0.3 ton of sediment,
- 1 pound of phosphorus,
- 4 pounds of nitrogen with surface runoff, and
- 11 pounds of nitrogen in subsurface flows.

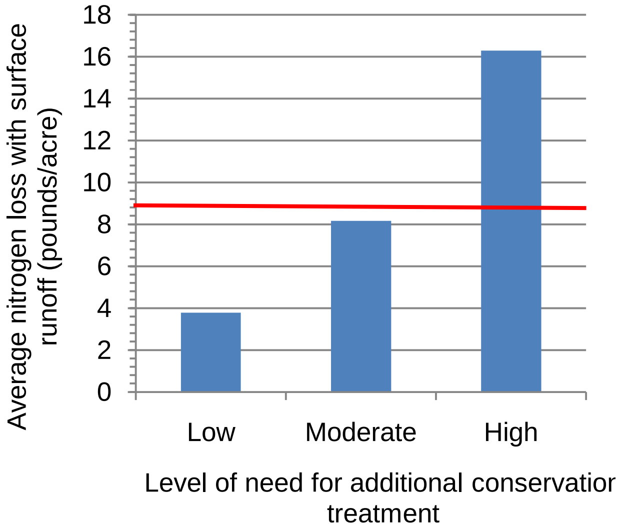
While gains can be obtained by adding conservation practices to some of these acres, additional conservation treatment would reduce field losses by only a small amount.

Figure 65. Average per-acre sediment loss for three levels of conservation treatment need for one or more resource concerns, Chesapeake Bay Region



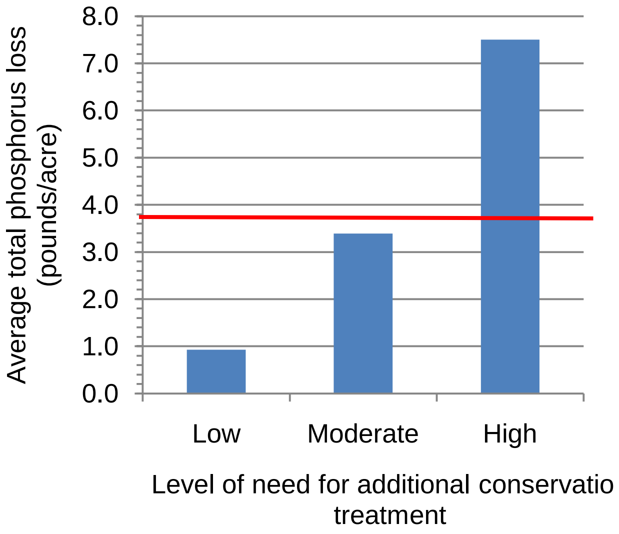
Note: The average sediment loss for all cropped acres is 1.18 tons per acre per year, shown in red.

Figure 66. Average per-acre nitrogen loss with surface runoff for three levels of conservation treatment need for one or more resource concerns, Chesapeake Bay Region



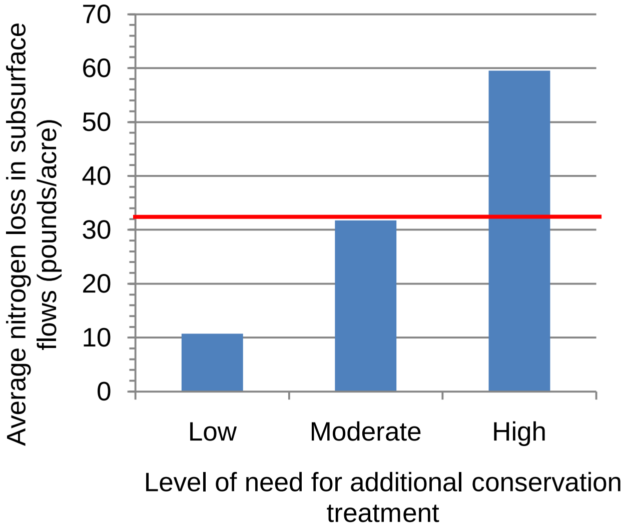
Note: The average nitrogen loss with surface runoff for all cropped acres is 8.8 pounds per acre per year, shown in red.

Figure 67. Average per-acre phosphorus lost to surface water for three levels of conservation treatment need for one or more resource concerns, Chesapeake Bay Region



Note: The average phosphorus lost to surface water for all cropped acres is 3.67 pounds per acre per year, shown in red.

Figure 68. Average per-acre nitrogen loss in subsurface flow pathways for three levels of conservation treatment need for one or more resource concerns, Chesapeake Bay Region



Note: The average nitrogen loss in subsurface flow pathways for all cropped acres is 32.7 pounds per acre per year, shown in red.

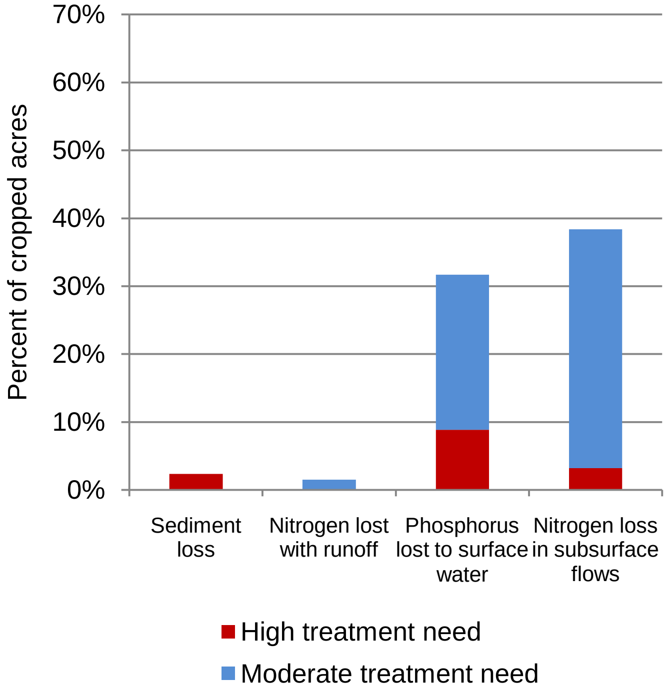
Table 28. Baseline conservation condition model simulation results for subsets of under-treated and adequately treated acres in the Chesapeake Bay region

Model simulated outcome	**Acres with a *low* need for treatment**	**Acres with a *moderate* need for treatment**	**Acres with a *high* need for treatment**	**All acres**
Cultivated cropland acres in subset	871,976	2,597,927	809,997	4,279,900
Percent of acres	20.4%	60.7%	18.9%	100%
Water flow				
Average annual surface runoff (inches)	4.9	5.1	5.2	5.1
Average annual subsurface water flow (inches)	11.1	10.7	10.3	10.7
Erosion and sediment loss				
Average annual wind erosion (tons/acre)	0.026	0.031	0.016	0.027
Average annual sheet and rill erosion (tons/acre)	0.4	1.0	1.7	1.0
Average annual sediment loss at edge of field due to water erosion (tons/acre)	0.3	1.0	2.5	1.2
Soil organic carbon				
Average annual change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)	-12	-17	-75	-27
Nitrogen loss				
Nitrogen applied (pounds/acre)	57	97	133	95
Nitrogen in crop yield removed at harvest (pounds/acre)	86	84	81	84
Total nitrogen loss for all pathways (pounds/acre)	20	49	87	50
Average annual loss of nitrogen through volatilization (pounds/acre)	5	7	8	7
Average annual nitrogen returned to the atmosphere through denitrification processes (pounds/acre)	1	1	3	2
Average annual loss of nitrogen with surface runoff, including waterborne sediment (pounds/acre)	4	8	16	9
Average annual nitrogen loss in subsurface flows (pounds/acre)	11	32	60	33
Phosphorus loss				
Phosphorus applied (pounds/acre)	15.3	24.2	39.3	25.2
Total phosphorus loss for all pathways (pounds/acre)	1.0	3.5	7.6	3.8
Loss of phosphorus with surface runoff, including waterborne sediment (pounds/acre)	0.9	3.4	7.5	3.7
Pesticide loss				
Average annual mass loss of pesticides for all pathways (grams of active ingredient/hectare)	7.6	14.4	22.5	14.6
Average annual surface water pesticide risk indicator for aquatic ecosystem	1.0	1.7	2.7	1.8
Average annual surface water pesticide risk indicator for humans	0.2	0.4	0.6	0.4

Conservation treatment needs if cover crops were used

The “what if” scenario simulating full adoption of cover crops (see appendix C) indicated that if *all* acres in the region had cover crops in use, conservation treatment needs would have been much lower. Acres with a high level of treatment need would have been only 11 percent of cropped acres instead of 19 percent, and acres with a moderate level of treatment need would have been 42 percent of cropped acres instead of 61 percent. The breakdown of under-treated acres by resource concern is shown in figure 69 for comparison to the same breakdown for the baseline conservation condition in figure 63. To the extent that cover crops are being used more now than during 2003–06, conservation treatment needs will be less today than the levels estimated in this study.

Figure 69. Percent of cropped acres that would have been determined to be under-treated in the Chesapeake Bay Region if all acres in the region had cover crops in use, by resource concern



Conservation treatment needs by cropping systems

The breakdown of under-treated acres by cropping system showed a proportionate distribution of under-treated acres among cropping systems, shown in table 29.

For the critical under-treated acres (acres with a high need for treatment), however, a disproportionately higher percentage occurs for two cropping systems—hay-crop mixes and corn only—indicating that these cropping systems tend to occur more frequently on the more vulnerable acres within the region.

Conservation treatment needs by subregions

Percentages of the under-treated acres in the Chesapeake Bay region that are in each subregion are close to the same percentages of the region’s cultivated cropland in each subregion, indicating that under-treated acres are spread proportionately throughout the region (table 30).

Critical under-treated acres, however, are disproportionately high in the Susquehanna River subregion relative to the percentage of cropped acres. This subregion has 41 percent of the cropped acres in the watershed and 69 percent of the critically under-treated acres. Critical under-treated acres are disproportionately low in the Upper Chesapeake subregion relative to the percentage of cropped acres.

Table 29. Under-treated acres by cropping system in the Chesapeake Bay region

		Critical under-treated acres			All under-treated acres		
Subregion name	Percent of cropped acres in Chesapeake Bay region	Acres	Percent of acres in Chesapeake Bay region	Percent of acres in cropping system	Acres	Percent of acres in Chesapeake Bay region	Percent of acres in cropping system
Corn-soybean only	27	208,111	26	18	933,499	27	79
Corn-soybean with close grown crops	19	137,046	17	17	683,444	20	82
Corn only	16	212,227	26	31	595,083	17	86
Hay-crop mix	16	170,146	21	25	545,460	16	79
Corn and close grown crops	7	63,386	8	21	263,845	8	89
Remaining mix of crops	4	11,681	1	7	139,192	4	79
Soybean only	4	0	0	0	40,184	1	25
Vegetable or tobacco with or without other crops	3	7,400	1	5	125,164	4	90
Soybean-wheat only	3	0	0	0	82,053	2	66
Total	100	809,997	100	19	3,407,924	100	80

Note: Percents may not add to totals because of rounding.

Table 30. Under-treated acres for the four subregions in the Chesapeake Bay region

			Critical under-treated acres			All under-treated acres		
Sub-region code	**Subregion name**	Percent of cropped acres in Chesapeake Bay region	Acres	Percent of acres in Chesapeake Bay region	Percent of acres in subregion	Acres	Percent of acres in Chesapeake Bay region	Percent of acres in subregion
0205	Susquehanna River	41	558,625	69	32	1,464,251	43	84
0206	Upper Chesapeake Bay	28	92,499	11	8	862,878	25	73
0207	Potomac River	16	120,517	15	18	590,263	17	86
0208	Lower Chesapeake Bay	16	38,356	5	6	490,533	14	73
	Total	100	809,997	100	19	3,407,924	100	80

Note: Percents may not add to totals because of rounding.

Chapter 6
Assessment of Potential Field-Level Gains from Further Conservation Treatment

Four conservation treatment scenarios were simulated to evaluate the potential gains from further conservation treatment in the Chesapeake Bay region:

- Treatment of the 0.8 million critical under-treated acres (acres with a high need for conservation treatment) with water erosion control practices.
- Treatment of all 3.4 million under-treated acres (acres with a high or moderate need for conservation treatment) with water erosion control practices.
- Treatment of the 0.8 million critical under-treated acres with nutrient management practices in addition to water erosion control practices to address nutrient losses.
- Treatment of all 3.4 million under-treated acres with nutrient management practices in addition to water erosion control practices to address nutrient losses.

The simulated levels of conservation treatment were designed to add the additional practices needed to complete the existing suite of practices so as to reduce sediment and nutrient losses at the edge of the field to acceptable levels. The existing practices were augmented with additional practices to—

- avoid or limit the potential for loss by using nutrient management practices (appropriate rate, timing, *and* method) on *all* crops in the rotation;
- control overland flow where needed; and
- trap materials leaving the field using appropriate edge-of-field mitigation where absent.

The simulated additional treatment consists of traditional conservation practices and treatment options that have been implemented over the past 10 years and would be expected to be found in current NRCS conservation plans.

The simulated treatment levels are intended to maintain the production capacity within the region to produce crops for food, fiber, forage, and fuel. The simulated practices produced small decreases in acres in crop production and crop yields.

The specific conservation practices used in the simulated treatments are not intended to be a prescription for how to construct conservation plans, but rather are a general representation of sets or suites of conservation practices that could be used to address multiple resource concerns. In actual planning situations a variety of alternative practice scenarios would be presented to the producer and selections would be based on the level of treatment need, cost of conservation implementation, impact on production goals, and preferences of the farm operator.

The level of conservation treatment is simulated to show potential environmental benefits, but is not designed to achieve specific environmental protection goals. Treatment scenarios were also not designed to represent actual program or policy options for the Chesapeake Bay region. Economic and programmatic aspects--such as producer costs, conservation program costs, and capacity to deliver the required technical assistance--were not considered in the design of the treatment scenarios.

Conservation crop rotations were not included in the treatment scenarios because of the criteria to maintain crop acres and preserve current market value and yield for the region. Nevertheless, crop rotations that are conducted specifically for the purpose of reducing average annual losses of sediment and nutrients from farm fields have a high potential to further improve crop nutrient efficiency and reduce contaminant loadings.

For the same reason, long-term conserving cover was not included in the treatment scenarios. Long-term conserving cover represents the ultimate conservation treatment for acres that are highly vulnerable to sediment and nutrient loss. Enrolling more cultivated cropland acres in programs that provide the economic incentives for long-term conserving cover may be necessary in some areas to meet water quality goals for environmental protection.

Pesticide management was also not addressed in the treatment scenarios. While erosion control practices influence pesticide loss, significant reductions in pesticide risk within the region will require more intensive Integrated Pest Management (IPM) practices, including pesticide substitutions. Simulation of additional IPM and any associated pesticide substitutions is site specific and requires more information about the sample fields than was available from the farmer survey.

Simulation of Additional Water Erosion Control Practices

Erosion and surface water runoff treatment consists of structural and vegetative practices that slow runoff water and capture contaminants that it may carry. Practices were added where needed (summarized in table 31) according to the following rules.

- **In-field mitigation:**
    - Terraces were added to all sample points with slopes greater than 6 percent, and to those with slopes greater than 4 percent *and* a high potential for excessive runoff (hydrologic soil groups C or D). Although terraces may be too expensive or impractical to implement in all cases, they serve here as a surrogate for other practices that control surface water runoff.
    - Contouring or stripcropping (overland flow practices) was added to all other fields with slope greater than 2 percent that did not already have those practices and did not have terraces.
    - Concentrated flow practices were not applied since they occur on unique landscape situations within the field; landscape data other than slope and slope length were not available for CEAP sample points.

- **Edge-of-field mitigation:**
    - Fields adjacent to water received a riparian buffer, if one was not already present.
    - Fields not adjacent to water received a filter strip, if one was not already present.

In addition, the implementation of structural and vegetative practices is simulated by an adjustment in the land condition parameter used to estimate the NRCS Runoff Curve Number (RCN). The RCN is an empirical parameter used in surface hydrology for predicting direct runoff or infiltration. The hydrologic condition (a component in the determination of the RCN) was adjusted from "poor" to "good" for sample points where these additional practices were simulated.

Cover crops were not added. Similarly, tillage management was not altered in the simulation of conservation treatment.

Simulation of Additional Nutrient Management Practices

The nutrient management treatment scenario consists of additional nutrient management practices where needed *in addition to* the water erosion control practices. The nutrient management practices simulated the application of nutrients at an appropriate rate, in an appropriate form, at appropriate times, and using an appropriate method to provide sufficient nutrients for crop growth while minimizing losses to the environment. Simulation of nutrient management required changes to nutrient applications for one or more crops on all but about 6 percent of the acres (see table 9).

Specific rules for application timing

The goal for appropriate timing is to apply nutrients close to the time when the plant is likely to require them, thereby minimizing the opportunity for loss from the field. Rules for the timing of nutrient applications (both nitrogen and phosphorus) are:

- All commercial fertilizer applications were adjusted to 14 days prior to planting, except for acres susceptible to leaching loss.
- For acres susceptible to leaching loss (hydrologic soil group A, soils with sandy textures, or tile drained fields), nitrogen was applied in split applications, with 25 percent of the total application 14 days before planting and 75 percent 30 days after planting.
- Manure applications during winter months (December, January, February, and March) were moved to 14 days pre-plant or April 1, whichever occurs first. This rule allows for late March applications of manure in the warmer climates of the Chesapeake Bay region. April 1 is near the period when the soils warm and become biologically active. However, this late date could begin to pressure manure storage capacities and it is recognized that this could create storage problems.

In the baseline condition, about 20 percent of the cropped acres in the Chesapeake Bay region receive fertilizer applications in the fall for at least one spring-planted row crop in the rotation. The only fall application of nutrients simulated in the nutrient management treatment scenario was for fall seeded crops that received a starter fertilizer at planting time.

Table 31. Summary of additional structural practices simulated for under-treated acres to assess the potential for gains from additional conservation treatment in the Chesapeake Bay region

	Critical under-treated acres (acres with a high level of treatment need)		Non-critical under-treated acres (acres with a moderate level of treatment need)		All under-treated acres	
Additional practice	Treated acres	Percent of total	Treated acres	Percent of total	Treated acres	Percent of total
Overland flow practice only	5,143	<1	41,971	2	47,115	1
Terrace only	19,744	2	41,940	2	61,684	2
Filter only	55,724	7	767,816	30	823,540	24
Filter plus overland flow practice	96,083	12	535,839	21	631,922	19
Filter plus Terrace	504,826	62	615,910	24	1,120,736	33
Buffer only	20,756	3	201,730	8	222,486	7
Buffer plus overland flow practice	56,858	7	131,006	5	187,864	6
Buffer plus Terrace	50,864	6	145,134	6	195,997	6
One or more additional practices	809,997	100	2,481,347	96	3,291,344	97
No structural practices	0	0	116,580	4	116,580	3
Total	809,997	100	2,597,927	100	3,407,924	100

Note: Percents may not add to totals because of rounding.

Specific rules for method of application

If the method of application was other than incorporation then fertilizer and manure applications became incorporated or injected. Incorporation reduces the opportunity for nutrients on the soil surface to be carried away in the soluble form or attached to eroding particles. For manure applications on no-till fields, if the manure was in liquid or slurry form and had been sprayed/broadcast applied it was changed to injected or placed under the soil surface. Manure of solid consistency was incorporated by disking without regard to the tillage management type. If the tillage type had been originally no-till, the incorporation of the manure changed the tillage type to mulch tillage.

Specific rules for the form of application

If the tillage type was no-till, commercial fertilizer was changed to a form that could be knifed or injected below the soil surface. The change in form did not change the ammonia or nitrate ratio of the fertilizer.

Specific rules for the rate of nutrient applied

All nitrogen application rates for all crops except cotton and small grain crops were reduced to 1.2 times the crop removal rate. The 1.2 ratio is in the range of rates recommended by many of the Land Grant Universities. This rate replaces some of the environmental losses that occur during the cropping season, and also accounts for the savings in nutrients due to improved application timing and implementation of water erosion control practices.

For small grain crops (wheat, barley, oats, rice, rye, buckwheat, emmer, spelt, and triticale), nitrogen applications were reduced to 1.5 times the crop removal rate.

For cotton, nitrogen applications were reduced to 50 pounds per bale for sample points with application rates exceeding 50 pounds per bale.

For phosphorus, the application rates were adjusted to be equal to 1.1 times the amount of phosphorus removed in the crop at harvest over the crop rotation.

Potential for Field-Level Gains

Treatment of the 0.8 million critical under-treated acres

According to the model simulation, treatment of the 0.8 million critical under-treated acres with water erosion control practices would nearly eliminate sediment loss for these acres and dramatically reduce nitrogen and phosphorus lost to surface water, as shown in table 32. Sediment loss would be reduced to an annual average of about 0.2 ton per acre per year for these acres, a 93-percent reduction. Nitrogen loss with surface runoff would be reduced to 4.5 pounds per acre per year on average (73-percent reduction), and phosphorus lost to surface water would be reduced to 3.9 pounds per acre per year (48-percent reduction). However, the re-routing of surface water to subsurface flow pathways would reduce nitrogen loss in subsurface flows by only 1 percent, on average, for these acres.

The addition of nutrient management had little additional effect on sediment loss or nitrogen loss with surface runoff, but was effective in reducing nitrogen loss in subsurface flows and phosphorus lost to surface water (table 32). Nitrogen loss in subsurface flows for these acres would be reduced 59 percent compared to losses simulated for the baseline conservation condition. Phosphorus lost to surface water would be reduced 65 percent compared to the baseline condition for these acres.

These results support the conclusion drawn from the assessment of the effects of conservation practices that nutrient management practices need to be paired with erosion control practices to obtain significant reductions in the loss of soluble nutrients.

Table 33 presents estimates of how treatment of only the 0.8 million critical under-treated acres in the region would reduce *overall* edge-of-field losses *for the region as a whole*. These results were obtained by combining treatment scenario model results for the 0.8 million acres with model results from the baseline conservation condition for the remaining acres. Treating the 0.8 million critical under-treated acres with soil erosion control practices *and* nutrient management practices would, for the region as a whole—

- reduce sediment loss in the region by 37 percent on average, compared to the baseline conservation condition;
- reduce total nitrogen loss by 20 percent:
    - reduce nitrogen loss with surface runoff (sediment adsorbed and soluble) by 27 percent, and
    - reduce nitrogen loss in subsurface flows by 20 percent;
- reduce phosphorus lost to surface water (sediment adsorbed and soluble) by 25 percent, and
- reduce environmental risk from loss of pesticide residues by 4 percent.

Treatment of all 3.4 million under-treated acres

Simulation results for only the 3.4 million under-treated acres are presented in table 34 and results for the region as a whole are presented in table 35.

Table 34 shows that per-acre percent reductions of sediment and nutrient loss due to additional practices would be less on average than those for the 0.8 million most vulnerable under-treated acres. The 3.4 million under-treated acres include 2.6 million acres with a moderate need for treatment that are less vulnerable than the critical under-treated acres. The percent reductions *for the region as a whole* by treating 2.6 million additional acres, however, would be much higher, as shown in table 35.

Table 32. Conservation practice effects for additional treatment of 0.8 million critical under-treated acres (acres with a high need for conservation treatment) in the Chesapeake Bay region

	Baseline conservation condition	Treatment with erosion control practices		Treatment with erosion control and nutrient management practices	
Model simulated outcome	Average annual amount	Average annual amount	Percent reduction	Average annual amount	Percent reduction
Water flow					
Surface water runoff (inches)	5.2	4.4	15%	4.4	15%
Subsurface water flow (inches)	10.3	11.0	-6%	11.0	-6%
Erosion and sediment loss					
Wind erosion (tons/acre)	0.016	0.014	11%	0.014	10%
Sheet and rill erosion (tons/acre)	1.71	0.58	66%	0.59	66%
Sediment loss at edge of field due to water erosion (tons/acre)	2.52	0.17	93%	0.18	93%
Soil organic carbon					
Change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)	-75	1	--	-20	--
Nitrogen					
Nitrogen applied (pounds/acre)	133	128*	3%	79	40%
Nitrogen in crop yield removed at harvest (pounds/acre)	81	79	1%	74	8%
Total nitrogen loss for all pathways except harvest (pounds/acre)	87.2	74.3	15%	34.6	60%
Loss of nitrogen with surface runoff, including waterborne sediment (pounds/acre)	16.3	4.5	73%	3.7	77%
Nitrogen loss in subsurface flows (pounds/acre)	59.5	58.7	1%	24.6	59%
Phosphorus					
Phosphorus applied (pounds/acre)	39.3	38.2	3%	28.6	27%
Total phosphorus loss for all pathways except harvest (pounds/acre)	7.6	4.0	48%	2.7	64%
Loss of phosphorus to surface water, including waterborne sediment (pounds/acre)	7.5	3.9	48%	2.6	65%
Pesticide loss					
Mass loss of pesticides for all pathways (grams of active ingredient/hectare)	22.5	12.0	47%	12.2	46%
Surface water pesticide risk indicator for aquatic ecosystems	2.74	2.34	15%	2.39	13%
Surface water pesticide risk indicator for humans	0.55	0.46	17%	0.47	14%

* Total nitrogen applied was less in the treatment scenario than in the baseline because a small fraction of the field was removed from production to simulate use of additional edge-of-field buffer and filtering practices. This also explains the small decrease in nitrogen in the crop yield at harvest.

Note: Values reported in this table are for the 0.8 million critical under-treated acres only. Percent reductions are with respect to the baseline conservation condition.

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text.

Table 33. Conservation practice effects for the region as a whole* after additional treatment of 0.8 million critical under-treated acres (acres with a high need for conservation treatment) in the Chesapeake Bay region

	Baseline conservation condition	Treatment with erosion control practices		Treatment with erosion control and nutrient management practices	
Model simulated outcome	Average annual amount	Average annual amount	Percent reduction	Average annual amount	Percent reduction
Water flow					
Surface water runoff (inches)	5.1	4.9	3%	4.9	3%
Subsurface water flow (inches)	10.7	10.8	-1%	10.8	-1%
Erosion and sediment loss					
Wind erosion (tons/acre)	0.027	0.027	1%	0.027	1%
Sheet and rill erosion (tons/acre)	0.99	0.78	22%	0.78	21%
Sediment loss at edge of field due to water erosion (tons/acre)	1.18	0.74	38%	0.74	37%
Soil organic carbon					
Change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)	-27	-12	--	-16	--
Nitrogen					
Nitrogen applied (pounds/acre)	95	94**	1%	85	11%
Nitrogen in crop yield removed at harvest (pounds/acre)	84	84	0%	83	1%
Total nitrogen loss for all pathways except harvest (pounds/acre)	50.2	47.7	5%	40.2	20%
Loss of nitrogen with surface runoff, including waterborne sediment (pounds/acre)	8.8	6.6	25%	6.4	27%
Nitrogen loss in subsurface flows (pounds/acre)	32.7	32.6	0%	26.1	20%
Phosphorus					
Phosphorus applied (pounds/acre)	25.2	25.0	1%	23.2	8%
Total phosphorus loss for all pathways except harvest (pounds/acre)	3.8	3.1	18%	2.8	25%
Loss of phosphorus to surface water, including waterborne sediment (pounds/acre)	3.7	3.0	19%	2.7	25%
Pesticide loss					
Mass loss of pesticides for all pathways (grams of active ingredient/hectare)	14.6	12.6	14%	12.6	13%
Surface water pesticide risk indicator for aquatic ecosystems	1.76	1.68	4%	1.69	4%
Surface water pesticide risk indicator for humans	0.42	0.41	4%	0.41	4%

* Results presented for the region as a whole combine model output for the 0.8 million treated acres with model results from the baseline conservation condition for the remaining acres.

** Total nitrogen applied was less in the treatment scenario than in the baseline because a small fraction of the field was removed from production to simulate use of additional edge-of-field buffer and filtering practices.

Note: Percent reductions are with respect to the baseline conservation condition.

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text.

Table 34. Conservation practice effects for additional treatment of 3.4 million under-treated acres (acres with a high or moderate need for conservation treatment) in the Chesapeake Bay region

	Baseline conservation condition	Treatment with erosion control practices		Treatment with erosion control and nutrient management practices	
Model simulated outcome	Average annual amount	Average annual amount	Percent reduction	Average annual amount	Percent reduction
Water flow					
Surface water runoff (inches)	5.1	4.3	15%	4.3	15%
Subsurface water flow (inches)	10.6	11.2	-6%	11.2	-6%
Erosion and sediment loss					
Wind erosion (tons/acre)	0.027	0.025	10%	0.025	9%
Sheet and rill erosion (tons/acre)	1.14	0.44	61%	0.44	61%
Sediment loss at edge of field due to water erosion (tons/acre)	1.39	0.11	92%	0.11	92%
Soil organic carbon					
Change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)	-31	11	--	-5	--
Nitrogen					
Nitrogen applied (pounds/acre)	105	102*	3%	67	36%
Nitrogen in crop yield removed at harvest (pounds/acre)	83	82	2%	76	9%
Total nitrogen loss for all pathways except harvest (pounds/acre)	57.9	50.6	13%	25.3	56%
Loss of nitrogen with surface runoff, including waterborne sediment (pounds/acre)	10.1	3.3	67%	2.7	73%
Nitrogen loss in subsurface flows (pounds/acre)	38.3	38.0	1%	16.7	56%
Phosphorus					
Phosphorus applied (pounds/acre)	27.8	27.3	2%	21.3	23%
Total phosphorus loss for all pathways except harvest (pounds/acre)	4.5	2.6	42%	1.8	60%
Loss of phosphorus to surface water, including waterborne sediment (pounds/acre)	4.4	2.5	43%	1.7	62%
Pesticide loss					
Mass loss of pesticides for all pathways (grams of active ingredient/hectare)	16.4	10.3	37%	10.5	36%
Surface water pesticide risk indicator for aquatic ecosystems	1.95	1.71	12%	1.75	10%
Surface water pesticide risk indicator for humans	0.47	0.42	12%	0.43	9%

* Total nitrogen applied was less in the treatment scenario than in the baseline because a small fraction of the field was removed from production to simulate use of additional edge-of-field buffer and filtering practices. This also explains the small decrease in nitrogen in the crop yield at harvest.

Note: Values reported in this table are for the 3.4 million under-treated acres only. Percent reductions are with respect to the baseline conservation condition.

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text.

Table 35. Conservation practice effects for the region as a whole* after additional treatment of 3.4 million under-treated acres (acres with a high or moderate need for conservation treatment) in the Chesapeake Bay region

	Baseline conservation condition	Treatment with erosion control practices		Treatment with erosion control and nutrient management practices	
Model simulated outcome	Average annual amount	Average annual amount	Percent reduction	Average annual amount	Percent reduction
Water flow					
Surface water runoff (inches)	5.1	4.4	12%	4.4	12%
Subsurface water flow (inches)	10.7	11.2	-5%	11.2	-5%
Erosion and sediment loss					
Wind erosion (tons/acre)	0.027	0.025	8%	0.025	7%
Sheet and rill erosion (tons/acre)	0.99	0.44	56%	0.44	56%
Sediment loss at edge of field due to water erosion (tons/acre)	1.18	0.16	87%	0.16	87%
Soil organic carbon					
Change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)	-27	6	--	-6	--
Nitrogen					
Nitrogen applied (pounds/acre)	95	93**	3%	65	32%
Nitrogen in crop yield removed at harvest (pounds/acre)	84	83	2%	78	7%
Total nitrogen loss for all pathways except harvest (pounds/acre)	50.2	44.4	12%	24.2	52%
Loss of nitrogen with surface runoff, including waterborne sediment (pounds/acre)	8.8	3.4	61%	3.0	66%
Nitrogen loss in subsurface flows (pounds/acre)	32.7	32.4	1%	15.5	53%
Phosphorus					
Phosphorus applied (pounds/acre)	25.2	24.8	2%	20.0	21%
Total phosphorus loss for all pathways except harvest (pounds/acre)	3.8	2.3	40%	1.6	57%
Loss of phosphorus to surface water, including waterborne sediment (pounds/acre)	3.7	2.2	41%	1.5	59%
Pesticide loss					
Mass loss of pesticides for all pathways (grams of active ingredient/hectare)	14.6	9.8	33%	9.9	32%
Surface water pesticide risk indicator for aquatic ecosystems	1.76	1.57	11%	1.60	9%
Surface water pesticide risk indicator for humans	0.42	0.38	10%	0.39	8%

* Results presented for the region as a whole combine model output for the 3.4 million treated acres with model results from the baseline conservation condition for the remaining acres.

** Total nitrogen applied was less in the treatment scenario than in the baseline because a small fraction of the field was removed from production to simulate use of additional edge-of-field buffer and filtering practices. This also explains the small decrease in nitrogen in the crop yield at harvest.

Note: Percent reductions are with respect to the baseline conservation condition.

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text.

Treating all 3.4 million under-treated acres with soil erosion control practices *and* nutrient management practices would, for the region as a whole (table 35)—

- reduce sediment loss in the region by 87 percent on average, compared to the baseline conservation condition;
- reduce total nitrogen loss by 52 percent:
  - reduce nitrogen loss with surface runoff (sediment attached and soluble) by 66 percent, and
  - reduce nitrogen loss in subsurface flows by 53 percent;
- reduce phosphorus lost to surface water by 59 percent; and
- reduce environmental risk from loss of pesticide residues by 8-9 percent.

Comparison of treatment scenario results

The distributions of sediment and nutrient losses for the two levels of treatment are compared to the baseline conservation condition in the Chesapeake Bay region in figures 70 through 74. For perspective, the distribution of loss estimates if no conservation practices were in use, represented by the no-practice scenario, is also shown.

The distributions show how the number of acres with high losses could be reduced dramatically in the region, by treating the under-treated acres. For example, 16 percent of the acres in the Chesapeake Bay region exceed an annual average loss of sediment of 2 tons per acre per year in the baseline conservation condition. Model simulations indicate that treating the most vulnerable of the under-treated acres (0.8 million acres) with water erosion control practices would reduce the acres exceeding sediment loss of 2 tons per acre per year to 9 percent. Expanding the treatment to include all under-treated acres (3.4 million acres) would further reduce the acres exceeding annual sediment loss of 2 tons per acre to 1 percent (fig. 70).

Similar effects of additional treatment are shown for nitrogen lost with surface runoff and phosphorus lost to surface water. Treatment of critical under-treated acres with water erosion control *and* nutrient management would reduce the acres exceeding 15 pounds per acre of nitrogen lost with runoff from 18 percent for the baseline to 9 percent (fig. 72); treatment of all 3.4 million under-treated acres would nearly eliminate losses exceeding 15 pounds per acre. Acres exceeding 4 pounds per acre of phosphorus lost to surface water would be reduced from 30 percent for the baseline to 21 percent by treating the critical acres and to 9 percent by treating all under-treated acres (fig. 74).

For nitrogen loss in subsurface flow pathways, however, treatment of all 3.4 million under-treated acres would be required to reduce the overall regional edge-of-field losses to acceptable levels (fig. 73). About 34 percent of the acres in the region have nitrogen loss in subsurface flows greater than 25 pounds per acre per year for the baseline conservation condition. Treating the 0.8 million critical under-treated acres with nutrient management practices would reduce this percentage to 29 percent. Treatment of all 3.4 million under-treated acres would reduce the percentage to 12 percent.

Soil organic carbon would be minimally affected by the additional soil erosion control and nutrient management practices. Increases in soil organic carbon would occur largely because of savings of carbon that would otherwise be lost from the field through wind and water erosion. Figure 75 shows that the percentage of acres building soil organic carbon would increase from 43 percent for the baseline conservation condition to 48 percent with additional conservation treatment of the 3.4 million under-treated acres.

One of the objectives in constructing the treatment scenarios was to maintain the level of regional crop production. The removal of nitrogen at harvest serves as a useful proxy for crop yields and allows for aggregation over the mix of crops. The average annual amount of nitrogen removed at harvest would be reduced about 9 percent for the 3.4 million acres treated with additional soil erosion control and nutrient management practices (table 34), which represents a 7-percent reduction for the region as a whole (table 35). Figure 76 shows that the distribution of nitrogen removed at harvest would be slightly lower for the treatment scenario with nutrient management, but otherwise similar to the distribution for the baseline conservation condition.

Emerging technologies for reducing nitrogen loss from farm fields

The nutrient management treatment level simulated in this study represents feasible and proven conservation practices that are currently being successfully applied. There are, however, emerging conservation technologies that have the potential to further reduce nutrient loss from farm fields and provide even greater conservation benefits once the technologies become more widespread. These include—

- variable rate technology for precise nutrient application rates and placement methods;
- nitrogen use efficiency enhancers (time release and ammonia loss inhibitors);
- drainage water management that reduces late fall and early spring flushes of nitrate-laden drainage water; and
- constructed wetlands receiving surface water runoff from farm fields prior to discharge to streams and rivers.

New technologies that have the potential to increase crop yields without increasing nutrient inputs could further improve crop nutrient use efficiency and reduce offsite transport of nutrients relative to the level of crop production.

Figure 70. Estimates of average annual sediment loss for under-treated acres treated with water erosion control *and* nutrient management compared to the baseline conservation condition and the no-practice scenario, Chesapeake Bay region

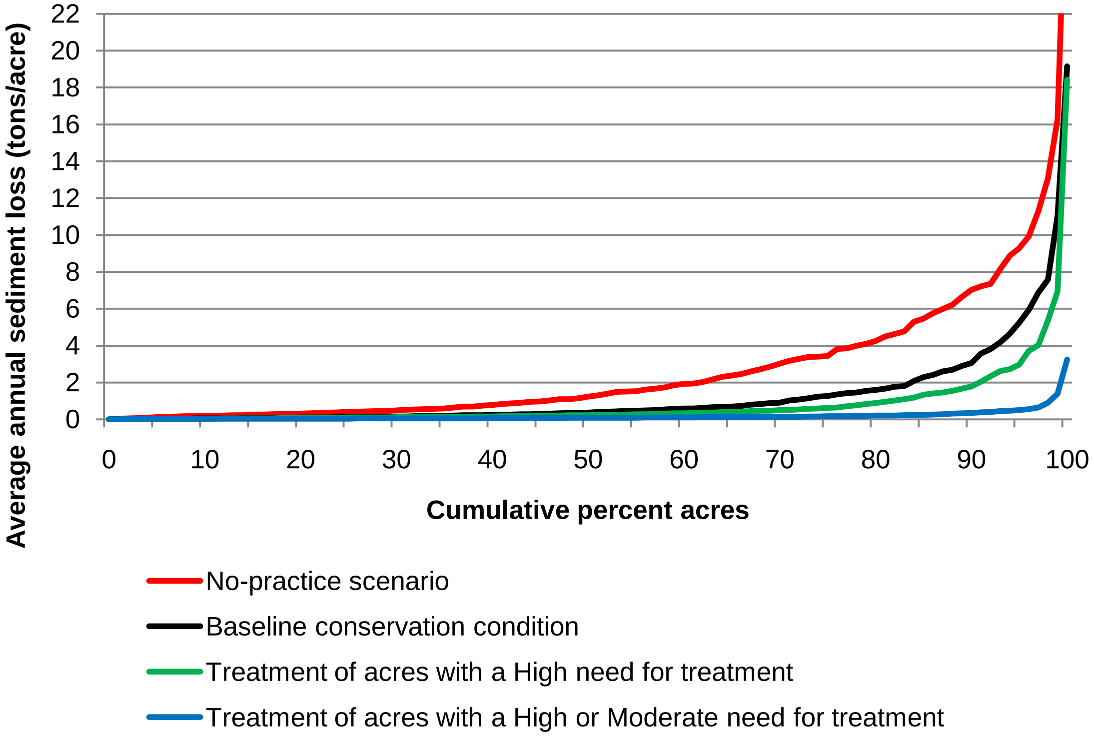


Figure 71. Estimates of average annual total nitrogen loss for under-treated acres treated with water erosion control *and* nutrient management compared to the baseline conservation condition and the no-practice scenario, Chesapeake Bay region

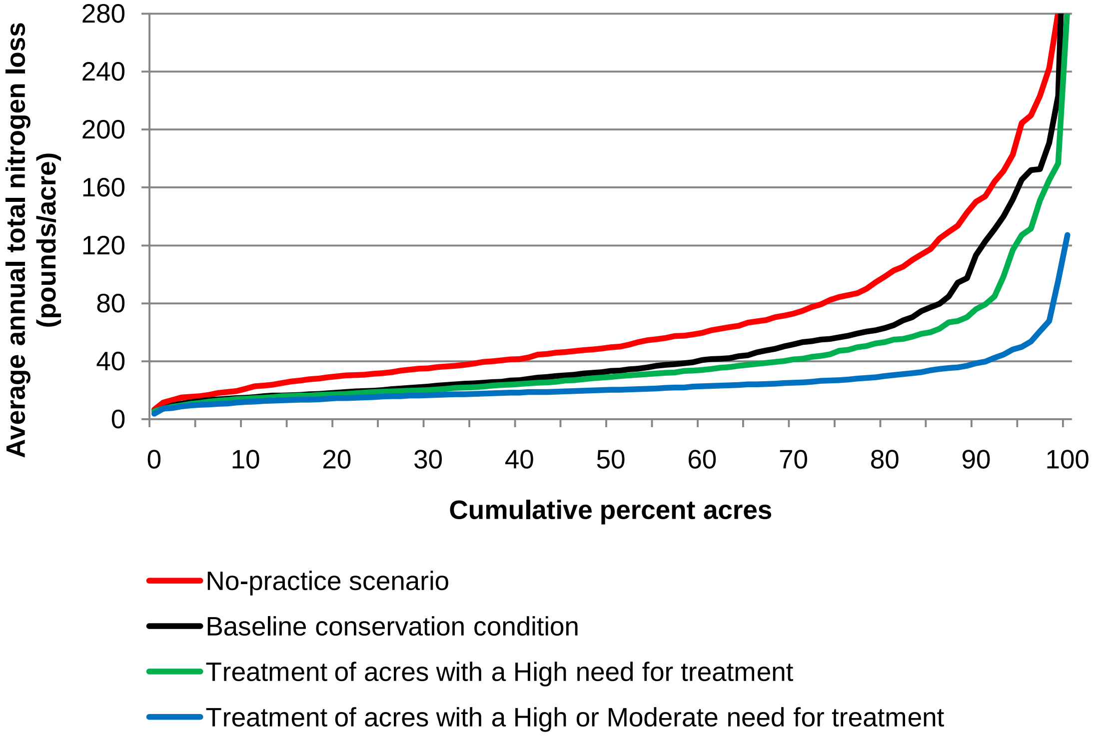


Figure 72. Estimates of average annual loss of nitrogen with surface runoff for under-treated acres treated with water erosion control *and* nutrient management compared to the baseline conservation condition and the no-practice scenario, Chesapeake Bay region

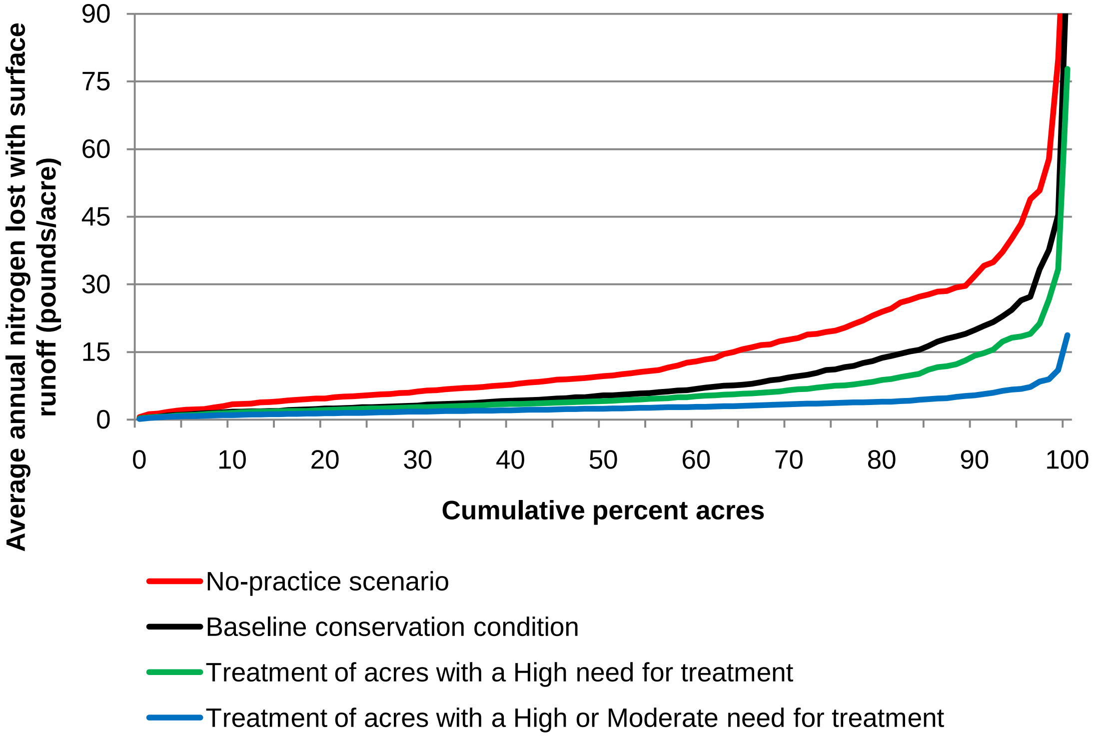


Figure 73. Estimates of average annual loss of nitrogen in subsurface flows for under-treated acres treated with water erosion control *and* nutrient management compared to the baseline conservation condition and the no-practice scenario, Chesapeake Bay region

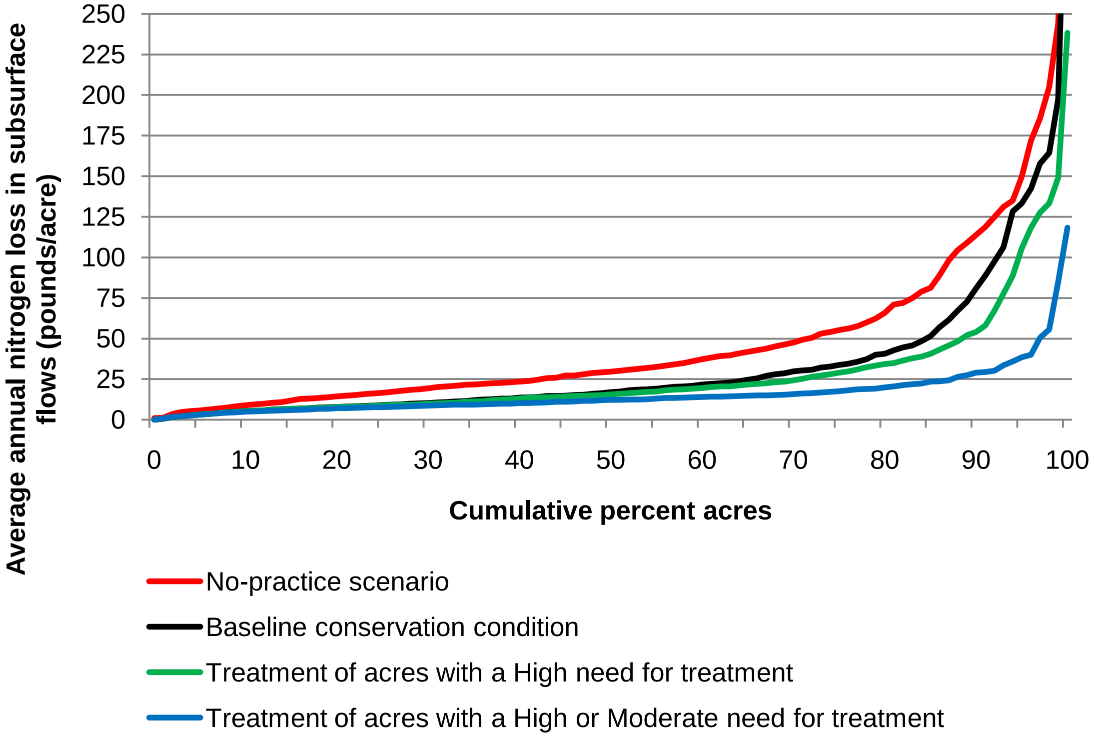
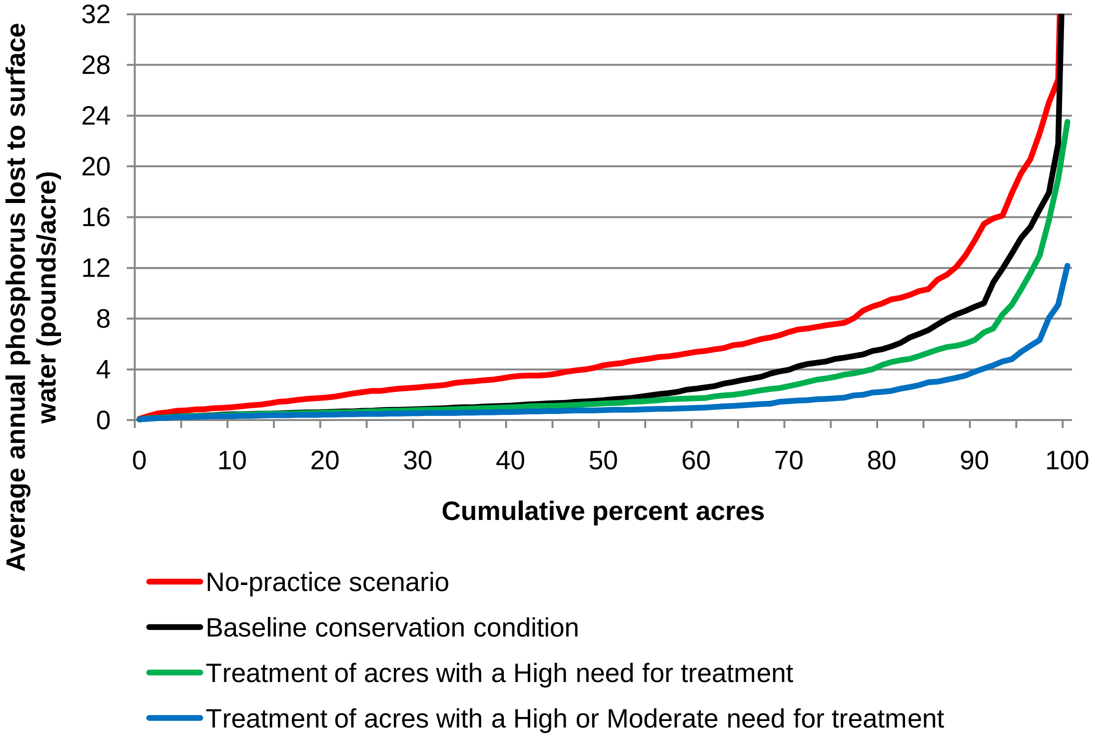


Figure 74. Estimates of average annual phosphorus lost to surface water (sediment attached and soluble)* for under-treated acres treated with water erosion control *and* nutrient management compared to the baseline conservation condition and the no-practice scenario, Chesapeake Bay region



* Soluble phosphorus lost to surface water includes phosphorus in water moving laterally within the soil into drainage systems (tile and surface drainage) and natural seeps.

Figure 75. Estimates of average annual change in soil organic carbon for under-treated acres treated with water erosion control *and* nutrient management compared to the baseline conservation condition and the no-practice scenario, Chesapeake Bay region

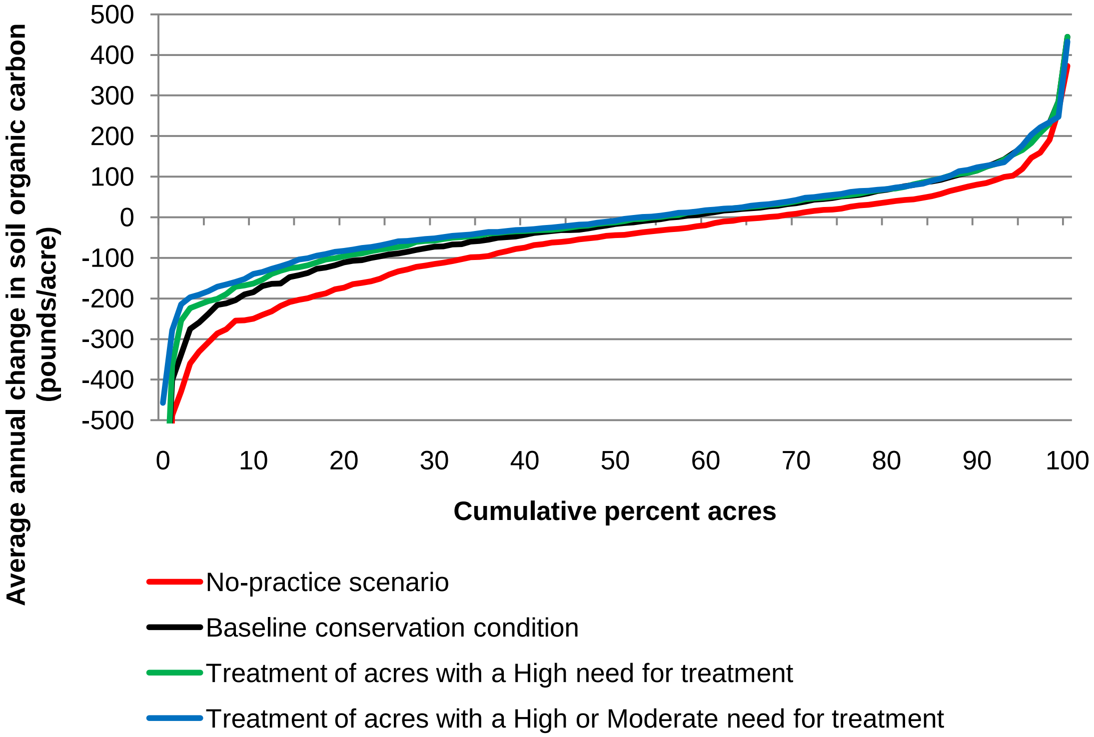
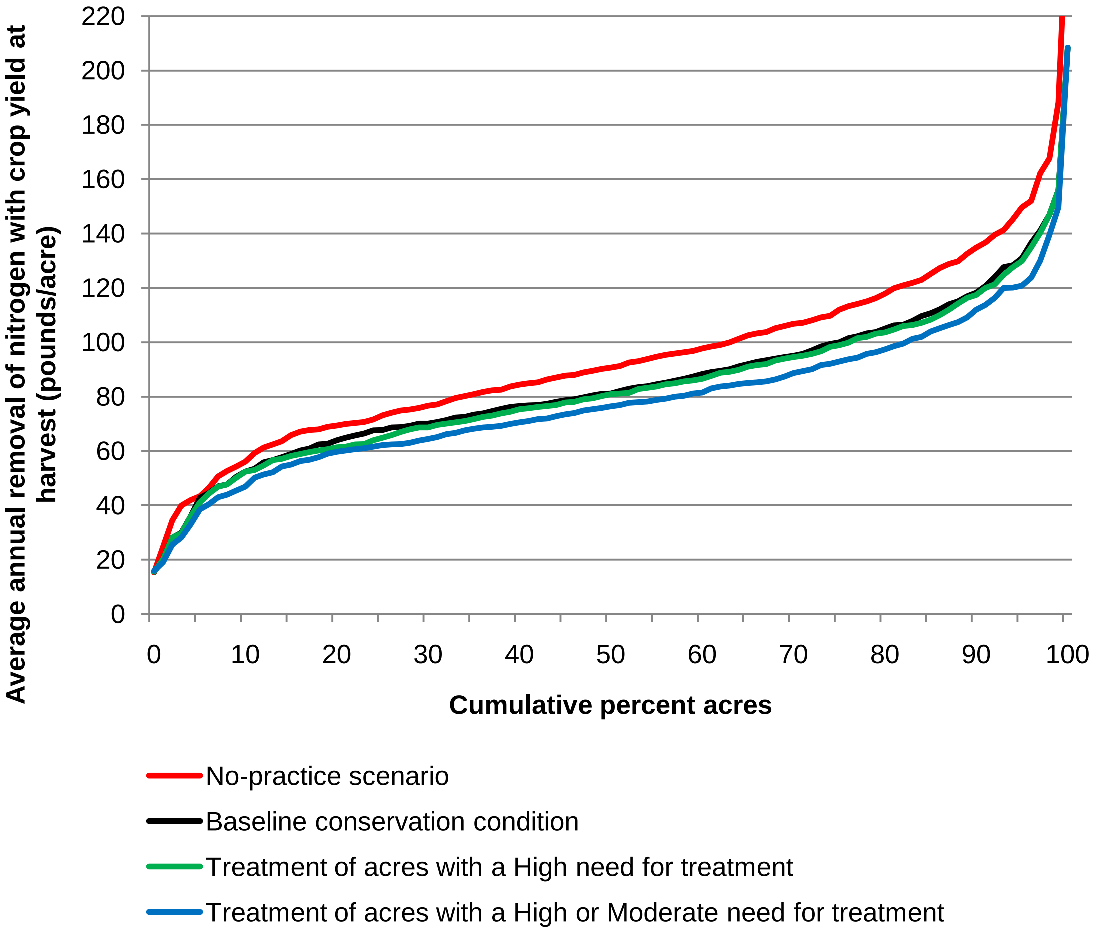


Figure 76. Estimates of average annual removal of nitrogen with crop yield at harvest for under-treated acres treated with water erosion control *and* nutrient management compared to the baseline conservation condition and the no-practice scenario, Chesapeake Bay region



Diminishing returns from additional conservation treatment

Tables 32 through 35 and figures 70 through 74 suggest diminishing returns from additional conservation treatment when the most vulnerable acres are treated first. These diminishing returns are shown explicitly in table 36, which includes estimates of the effects of additional conservation practices on the 0.9 million adequately treated acres in the Chesapeake Bay region. Diminishing returns to additional conservation treatment is demonstrated by comparing the average annual per-acre reductions in loss among the three groups of acres.

For example, conservation treatment of the 0.8 million critical under-treated acres would reduce sediment loss an average of 2.3 tons per acre per year on those acres. In comparison, additional treatment of the remaining 2.6 million under-treated acres would reduce sediment loss by about 1 ton per acre per year on those acres, and treatment of the remaining 0.9 million acres would reduce sediment loss by only 0.3 ton per acre per year on those acres, on average.

Similarly, diminishing returns were pronounced for nitrogen and phosphorus loss. Total nitrogen loss would be reduced by an average of 53 pounds per acre per year on the 0.8 million critical under-treated acres, compared to a reduction of 26 pounds per acre for the remaining 2.6 million under-treated acres and only 2 pounds per acre for the remaining 0.9 million acres.

Total phosphorus loss would be reduced by an average of 4.9 pounds per acre per year on the 0.8 million critical under-treated acres, compared to a reduction of 2.0 pounds per acre for the remaining 2.6 million under-treated acres and only 0.3 pound per acre for the remaining 0.9 million acres.

Nitrogen loss in subsurface flows would be reduced by an average of 35 pounds per acre per year on the 0.8 million critical under-treated acres, compared to a reduction of 17 pounds per acre for the remaining 2.6 million under-treated acres. However, the reduction for treatment of the remaining 0.9 million acres would average only 0.3 pound per acre.

Diminishing returns for reduction in environmental risk for pesticides are also evident, in spite of the fact that pesticide risk was not taken into account in the identification of under-treated acres and the assessment of conservation treatment needs.

Estimates of edge-of-field sediment and nutrient savings due to use of conservation practices

A convenient way to envision the potential gains from further conservation treatment is to contrast the potential sediment and nutrient savings to estimated savings for the conservation practices currently in use.

The no-practice scenario represents the maximum losses that would be expected without any conservation practices in use. Treatment of *all acres* with nutrient management and water erosion control practices was used to represent a “full-treatment” condition.

The difference in sediment and nutrient loss between these two scenarios was used to represent the maximum amount of savings possible for conservation treatment, which totaled 10.9 million tons of sediment, 99 thousand tons of nitrogen, and 10.2 thousand tons of phosphorus for the Chesapeake Bay region (fig. 77).

As shown in figure 77, about 57 percent of the potential sediment savings are accounted for by the conservation practices already in use, as represented by the baseline conservation condition. Additional treatment of the 0.8 million critical under-treated acres would account for another 17 percent of the potential sediment savings. Additional treatment of the remaining 2.6 million under-treated acres would account for about 23 percent of the potential savings. Further treatment of the 0.9 million adequately treated acres would account for the last 2 percent of potential savings.

For total phosphorus, 54 percent of the potential savings are accounted for by the conservation practices already in use, as represented by the baseline conservation condition. Additional treatment of the 0.8 million critical under-treated acres would account for another 19 percent of the potential phosphorus savings. Additional treatment of the remaining 2.6 million under-treated acres would account for another 26 percent of the potential savings. Only 1 percent of potential phosphorus savings could be realized through additional treatment of the 0.9 million adequately treated acres.

Less progress is evident for total nitrogen, and therefore the potential for savings with additional treatment is greater. The baseline conservation condition accounts for 43 percent of the potential savings from conservation treatment. Treatment of the 0.8 million critical under-treated acres would account for an additional 22 percent of the potential nitrogen savings. Treatment of the remaining 2.6 million under-treated acres would account for another 35 percent of the potential nitrogen savings. Only 1 percent of potential nitrogen savings could be realized through additional treatment of the 0.9 million adequately treated acres.

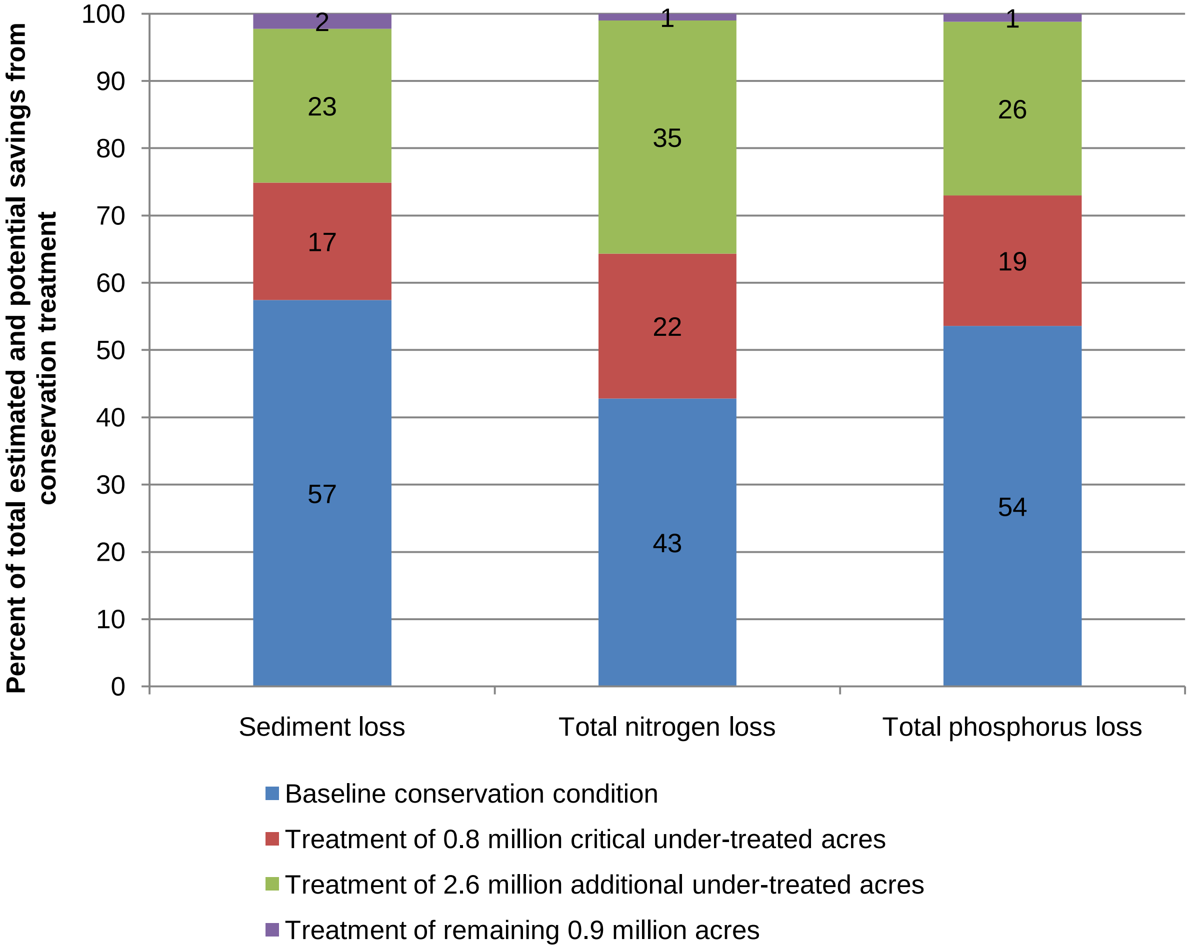
Table 36. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices for three groups of acres comprising the 4.3 million cropped acres in the Chesapeake Bay region

	Additional treatment for 0.8 million critical under-treated acres*			Additional treatment for 2.6 million non-critical under-treated acres*			Additional treatment for remaining 0.9 million acres		
	Baseline	Treatment scenario		Baseline	Treatment scenario		Baseline	Treatment scenario	
	Average annual amount	Average annual amount	Reduction	Average annual amount	Average annual amount	Reduction	Average annual amount	Average annual amount	Reduction
Water flow									
Surface water runoff (inches)	5.2	4.4	0.8	5.1	4.3	0.8	4.9	4.2	0.7
Subsurface water flow (inches)	10.3	11.0	-0.6	10.7	11.3	-0.7	11.1	11.7	-0.6
Erosion and sediment loss									
Wind erosion (tons/acre)	0.016	0.014	0.002	0.031	0.028	0.003	0.026	0.024	0.002
Sheet and rill erosion (tons/acre)	1.71	0.59	1.12	0.96	0.40	0.56	0.43	0.21	0.22
Sediment loss at edge of field due to water erosion (tons/acre)	2.52	0.18	2.34	1.04	0.09	0.95	0.35	0.07	0.28
Soil organic carbon									
Change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)	-75	-20	55**	-17	0	16**	-12	-1	10**
Nitrogen									
Nitrogen applied (pounds/acre)	133	79	53	97	63	33	57	53	3
Nitrogen in crop yield removed at harvest (pounds/acre)	81	74	7	84	77	8	86	83	3
Total nitrogen loss for all pathways except harvest (pounds/acre)	87.2	34.6	52.6	48.8	22.3	26.4	20.1	17.7	2.3
Loss of nitrogen with surface runoff, including waterborne sediment (pounds/acre)	16.3	3.7	12.6	8.2	2.4	5.7	3.8	2.0	1.8
Nitrogen loss in subsurface flows (pounds/acre)	59.5	24.6	35.0	31.7	14.3	17.4	10.8	10.5	0.3
Phosphorus									
Phosphorus applied (pounds/acre)	39.3	28.6	10.6	24.2	19.0	5.2	15.3	14.4	0.8
Total phosphorus loss for all pathways except harvest (pounds/acre)	7.6	2.7	4.9	3.5	1.5	2.0	1.0	0.7	0.3
Loss of phosphorus to surface water, including waterborne sediment (pounds/acre)	7.5	2.6	4.9	3.4	1.4	2.0	0.9	0.6	0.3
Pesticide loss									
Mass loss of pesticides for all pathways (grams of active ingredient/hectare)	22.5	12.2	10.3	14.4	10.0	4.4	7.6	6.2	1.3
Surface water pesticide risk indicator for aquatic ecosystem	2.74	2.39	0.35	1.70	1.55	0.15	1.03	0.94	0.09
Surface water pesticide risk indicator for humans	0.55	0.47	0.08	0.44	0.41	0.03	0.24	0.22	0.01

*Critical under-treated acres have a high need for additional treatment. Non-critical under-treated acres have a moderate need for additional treatment.

** Gain in soil organic carbon.

Figure 77. Comparison of estimated sediment, nitrogen, and phosphorus savings (field-level) that are due to practices in use in the baseline conservation condition and potential savings with additional water erosion control *and* nutrient management treatment of cropped acres in the Chesapeake Bay region



Tons of sediment, nitrogen, and phosphorus saved or potentially saved due to conservation practices

	Estimated savings due to conservation practice use (baseline conservation condition)	Potential savings from treatment of 0.8 million critical under-treated acres*	Potential savings from treatment of 2.6 million additional under-treated acres*	Potential savings from treatment of remaining 0.9 million acres*	Total estimated and potential savings from conservation treatment
Sediment	6,231,976	1,895,157	2,480,544	244,258	10,851,935
Nitrogen	42,395	21,312	34,305	1,014	99,027
Phosphorus	5,470	1,981	2,632	125	10,208

*Treatment with erosion control practices and nutrient management practices on all acres.

Note: Calculations do not include land in long-term conserving cover.

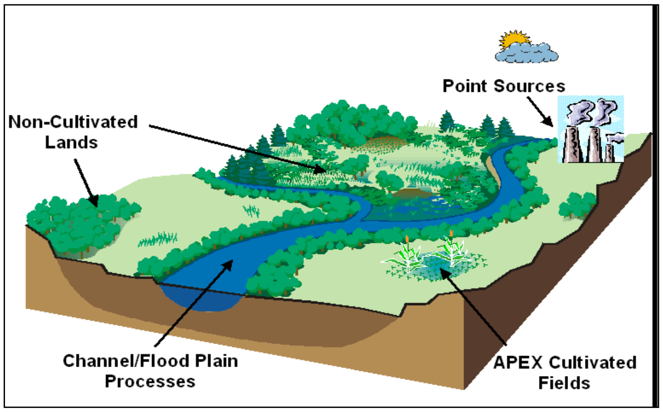
Note: Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

Chapter 7
Offsite Water Quality Effects of Conservation Practices

The National Water Quality Model—HUMUS/SWAT

Offsite estimates of water quality benefits were assessed using HUMUS/SWAT, a combination of the SWAT model and HUMUS (Hydrologic Unit Modeling for the United States) databases required to run SWAT at the watershed scale for all watersheds in the United States (Arnold et al. 1999; Srinivasan et al. 1998). SWAT simulates the transport of water, sediment, pesticides, and nutrients from the land to receiving streams and routes the flow downstream to the next watershed and ultimately to estuaries and oceans (fig. 78).

Figure 78. Sources of water flows, sediment, and agricultural chemicals simulated with HUMUS/SWAT



Like APEX, SWAT is a physical process model with a daily time step (Arnold and Fohrer 2005; Arnold et al. 1998; Gassman et al. 2007).[19] The hydrologic cycle in the model is divided into two parts. The land phase of the hydrologic cycle, or upland processes, simulates the amount of water, sediment, nutrients, and pesticides delivered from the land to the outlet of each watershed. The routing phase of the hydrologic cycle, or channel processes, simulates the movement of water, sediment, nutrients, and pesticides from the outlet of the upstream watershed through the main channel network to the watershed outlet.

Upland processes

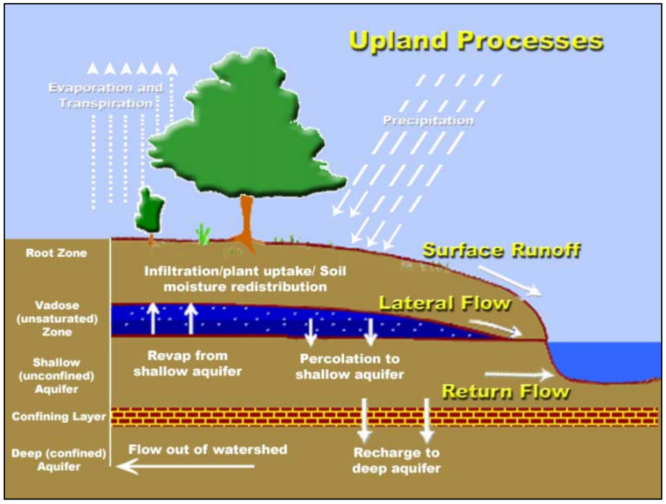
The water balance is the driving force for transport and delivery of sediment, nutrients, and pesticides from fields to streams and rivers. For this study, upland processes for non-cultivated cropland were modeled using SWAT, while source loads for cultivated cropland are estimated by APEX.

In SWAT, each watershed is divided into multiple Hydrologic Response Units (HRUs) that have homogeneous land use, management, and soil characteristics. An HRU is not a contiguous land area, but rather represents the percentage of the watershed that has the HRU characteristics. In this study, SWAT is used to simulate the fate and transport of water, sediment, nutrients, and pesticides for the following land use categories, referred to as HRUs:

- Pastureland
- Range shrub
- Range grass
- Urban
- Mixed forest
- Deciduous forest
- Evergreen forest
- Horticultural lands
- Forested wetlands
- Non-forested wetlands

Upland processes were modeled for each of these HRUs in each watershed (8-digit HUC) (fig. 79). The model simulates surface runoff estimated from daily rainfall; percolation modeled with a layered storage routing technique combined with a subsurface flow model; lateral subsurface flow; groundwater flow to streams from shallow aquifers, potential evapotranspiration; snowmelt; transmission losses from streams; and water storage and losses from ponds.

Figure 79. SWAT model upland simulation processes



Upland processes for cultivated cropland (including land in long-term conserving cover) were modeled using APEX as described in previous chapters. The weighted average of per-acre APEX model output for surface water delivery, sediment, nutrients, and pesticides was multiplied by the acres of cultivated cropland in the HUMUS database and used as SWAT model inputs for cultivated cropland for each 8-digit HUC. The acreage weights for the CEAP sample points were used to calculate the per-acre loads. (Several of the 8-digit watersheds in each region had too few CEAP sample points to reliably estimate edge-of-field per-acre loads. In these cases, the 6-digit per acre loads and sometimes the 4-digit per-acre loads were used to represent cultivated cropland.)

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[19] A complete description of the SWAT model can be found at http://www.brc.tamus.edu/swat/index.html.

Some land management activities were modeled in SWAT. No management was simulated for rangeland, forestland, urban land, or horticulture. For permanent hayland, the following management activities were simulated:

- Three hay cuttings were simulated per crop year.
- Hay was fertilized with nitrogen according to the crop need as determined by an auto-fertilization routine, which was set to grow the crop without undue nitrogen stress.
- For legume hay, phosphorus was applied at the time of planting (every fourth year) at a rate of 50 pounds per acre, followed by applications of 13 pounds per acre every other year.
- Manure was applied to hayland at rates estimated from probable land application of manure, estimated using the methods described in USDA/NRCS (2003).
- For hayland acres that land-use databases indicated were irrigated, water was applied at a frequency and rate defined by an auto-irrigation routine.

For pastureland, the following management activities were simulated:

- Four grass cuttings were simulated per year to simulate grazing.
- Pastureland was fertilized with nitrogen according to the crop need as determined by an auto-fertilization routine, which was set to grow grass without undue nitrogen stress.
- Manure was applied to pastureland at rates estimated from probable land application of manure as estimated in USDA/NRCS (2003).
- Manure nutrients from grazing animals were simulated for pastureland according to the density of pastured livestock as reported in the 2002 Census of Agriculture. Non-recoverable manure was estimated by subtracting recoverable manure available for land application from the total manure nutrients representing all livestock populations. Non-recoverable manure nutrients include the non-recoverable portion from animal feeding operations. Estimates of manure nutrients were derived from data on livestock populations as reported in the 2002 Census of Agriculture, which were available for each 6-digit HUC and distributed among the 8-digit HUCs on a per-acre basis.

A summary of the total amount of nitrogen and phosphorus applied to agricultural land in the model simulation, including nitrogen and phosphorus applied to cultivated cropland in the APEX modeling, is presented in table 37.[20] Manure nutrients from wildlife populations are not included

Urban Sources

Discharges from industrial and municipal wastewater treatment plants can be major sources of sediment and nutrients in some watersheds. For this study, the point source database developed for use in the Chesapeake Bay model was used. Point source loads are aggregated within each watershed and average annual loads input into SWAT at the watershed outlet.

Urban runoff is estimated separately for three categories of cover: 1) impervious surfaces such as buildings, parking lots, paved streets, etc., 2) impervious surfaces hydraulically connected to drainage systems such as storm drains, and 3) impervious surfaces not hydraulically connected to drainage systems. For estimating surface water runoff, a runoff curve number of 98 was used for impervious surfaces connected hydraulically to drainage systems and a composite runoff curve number was used for impervious surfaces not hydraulically connected to drainage systems. Sediment and nutrients carried with storm water runoff to steams and rivers were estimated using regression equations developed by Driver and Tasker (1988).

Sediment produced from construction sites was also simulated in SWAT. Construction areas were assumed to represent 3 percent of urban areas. Parameters in the soil input file were modified to produce surface runoff and sediment yield that mimicked the average sediment load from published studies on construction sites.

Not included in the point source data are 1) pseudo-point sources, such as confined animal feeding operations and fertilizer handling and distribution centers, 2) urban applications of nutrients and chemicals (lawns, golf-courses, etc.), or 3) small communities and homes not connected to sewer systems.

Atmospheric nitrogen deposition

Atmospheric deposition of nitrogen can be a significant component of the nitrogen balance. Nitrogen deposition data (loads and concentrations) were developed from the National Atmospheric Deposition Program/National Trends Network database (NAPD 2004). When a rainfall event occurs in the model simulation, the amount of rainfall is multiplied by the average ammonium and nitrate concentrations calculated for the watershed to account for wet deposition. An additional amount of ammonium and nitrate are added on a daily basis to account for dry deposition.

Routing and channel processes

SWAT simulates stream/channel processes including channel flood routing, channel sediment routing, nutrient and pesticide routing, and transformations modified from the QUAL2E model (fig. 80).

- **Flood routing**. As water flows downstream, some may be lost due to evaporation and transmission through the channel bed. Another potential loss is removal of water from the channel for agricultural or human use. Flow may be supplemented by rainfall directly on the channel and/or addition of water from point source discharges.

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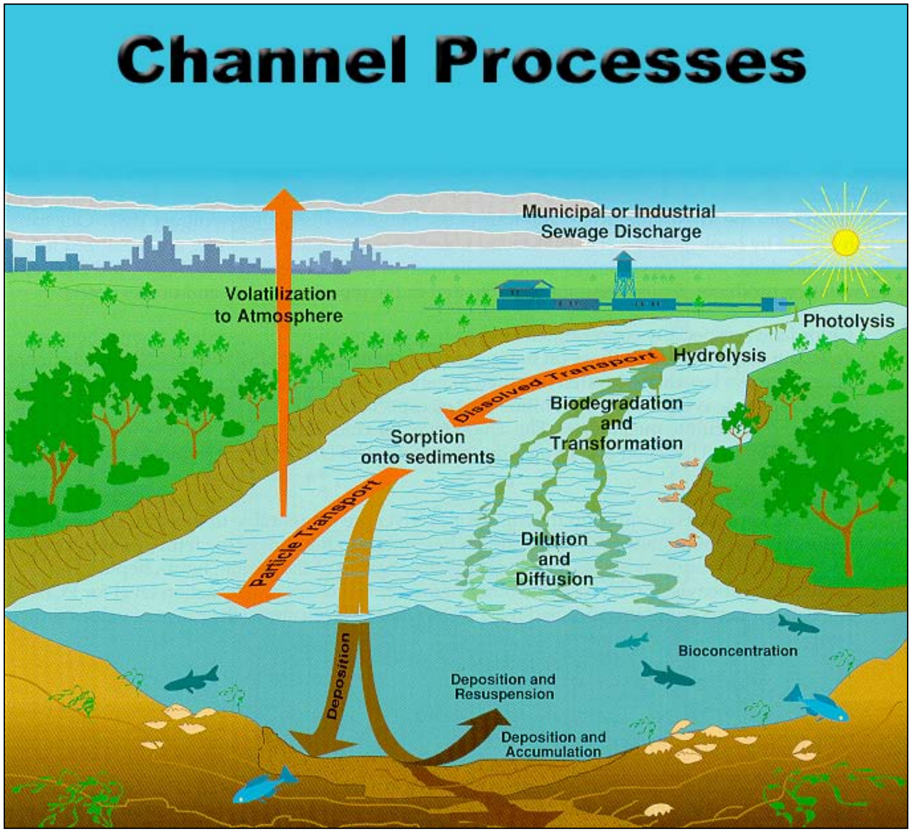
[20] For information on how manure nutrients were calculated for use in HUMUS modeling, see “Manure Loadings Used to Simulate Pastureland and Hayland in CEAP HUMUS/SWAT Modeling,” available at: http://www.nrcs.usda.gov/technical/nri/ceap/Cropland.html.

Table 37. Summary of commercial fertilizer and manure nutrients applied to agricultural land in HUMUS/SWAT (pastureland and hayland) and APEX (cultivated cropland) model simulations, Chesapeake Bay watershed.

Sub-region code	Subregion name	Commercial nitrogen fertilizer (tons/year)	Nitrogen from manure (tons/year)	Total nitrogen (tons/year)	Commercial phosphorus fertilizer (tons/year)	Phosphorus from manure (tons/year)	Total phosphorus (tons/year)
Cultivated cropland							
0205	Susquehanna River	50,296	38,805	89,102	11,035	14,422	25,456
0206	Upper Chesapeake Bay	34,097	13,611	47,708	6,122	4,192	10,314
0207	Potomac River	22,969	12,444	35,413	4,933	5,616	10,549
0208	Lower Chesapeake Bay	23,054	121	23,175	5,363	71	5,434
	Total	130,416	64,982	195,398	27,452	24,301	51,753
Hayland							
0205	Susquehanna River	22,681	3,196	25,876	2,774	1,446	4,220
0206	Upper Chesapeake Bay	787	309	1,096	110	142	252
0207	Potomac River	14,913	5,136	20,049	632	2,448	3,080
0208	Lower Chesapeake Bay	13,479	1,065	14,544	181	514	695
	Total	51,860	9,706	61,566	3,698	4,549	8,247
Pastureland and rangeland							
0205	Susquehanna River	8,532	36,160	44,693	3,150	13,496	16,646
0206	Upper Chesapeake Bay	1,880	9,091	10,971	822	4,000	4,821
0207	Potomac River	6,928	33,652	40,580	3,386	16,362	19,748
0208	Lower Chesapeake Bay	3,394	14,382	17,777	1,927	8,080	10,008
	Total	20,734	93,285	114,020	9,285	41,939	51,224

Figure 80. SWAT model channel simulation processes



- **Sediment routing**. The transport of sediment in the channel is controlled by the simultaneous operation of two processes, deposition and degradation. A stream power function was used to determine degradation as a function of channel slope and velocity. The maximum amount of sediment that can be transported from a reach segment is a function of the peak channel velocity. Available stream power is used to re-entrain loose and deposited material until all of the material is removed. Excess stream power causes bed degradation. Bed degradation is adjusted for streambed erodibility and cover.

- **Nutrient routing**. Nutrient transformations in the stream are controlled by the instream water quality component of the model. The model tracks nutrients dissolved in the stream and nutrients adsorbed to the sediment. Dissolved nutrients are transported with the water, while those sorbed to sediments are deposited with the sediment on the bed of the channel.

- **Pesticide routing**. As with nutrients, the total pesticide load in the channel is partitioned into dissolved and sediment-attached components. While the dissolved pesticide is transported with water, the pesticide attached to sediment is affected by sediment transport and deposition processes. Pesticide transformations in the dissolved and sorbed phases are governed by first-order decay relationships. The major in-stream processes simulated by the model are settling, burial, resuspension, volatilization, diffusion, and transformation.

Reservoirs alter the dynamics of a free-flowing river, resulting in different rates of sediment deposition and chemical transformations. SWAT includes routines for reservoirs that account for the hydrological aspects of reservoirs. Basic reservoir data such as storage capacity and surface area were obtained from the dams database.

- **Reservoir outflow**. A simple reservoir simulation approach was used in this study. It is a monthly target release-storage approach based on the storage capacity and flood seasons.

- **Sediment routing**. The concentration of sediment in the reservoir is estimated using a simple continuity equation based on volume and concentration of inflow, outflow, and water retained in the reservoir. Settling of sediment in the reservoir is governed by an equilibrium sediment concentration and the median sediment particle size. The amount of sediment in the reservoir outflow is the product of the volume of water flowing out of the reservoir and the suspended sediment concentration in the reservoir at the time of release.

- **Reservoir nutrients**. The model assumes that (1) the reservoir is completely mixed, (2) phosphorus is the limiting nutrient, and (3) total phosphorus is a measure of the trophic status. The phosphorus mass balance equation includes the concentration in the reservoir, inflow, outflow, and overall loss rate.

- **Reservoir pesticides**. The model partitions the system into a well-mixed surface water layer underlain by a well-mixed sediment layer for simulating the fate of pesticides. The pesticide is partitioned into dissolved and particulate phases in both the water and sediment layers. The major processes simulated by the model are loading, outflow, transformation, volatilization, settling, diffusion, resuspension, and burial.

Calibration

Delivery of surface water and subsurface water from upland processes (HRUs and CEAP sample points) was spatially calibrated for each watershed to ensure that water inputs to the SWAT model were in balance with long-term data on streamflow for the region. Water yields from HRUs and sample points were compared to long-term water yields estimated by USGS. Hydrologic parameters in APEX (cultivated cropland) and SWAT (HRUs) were adjusted separately for each 8-digit watershed until differences in the long-term water yield were minimized.[21]

The “background” scenario

An additional scenario was conducted to represent loadings that would be expected if no acres in the watershed were cultivated. These estimates were derived by simulating with APEX a grass-and-tree mix cover without any tillage or addition of nutrients or pesticides for all cultivated cropland acres in the watershed.[22] All SWAT modeling remained the same for this scenario. Thus, “background” loads include loads from all other land uses—hayland, pastureland, forestland, and urban land—as well as point sources. The results of this scenario are labeled “background” in tables and figures.

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[21] For a complete documentation of calibration procedures and results for the Chesapeake Bay region, see “Calibration and Validation for CEAP HUMUS” at http://www.nrcs.usda.gov/technical/nri/ceap/cropland.html.

[22] In a natural ecosystem, the vegetative cover would include a mix of species, which would continually change until a stable ecosystem was established. APEX allows for multiple species and simulates plant competition over time according to plant growth, canopy cover, vegetative form, and relative maturity or growth stage. The initial mix of species at the beginning of the 47-year simulation was similar to the mix of grasses and trees used to establish long-term conserving cover. Mixes included at least one grass and one legume. Over the 47-year simulation, the mix of grasses and trees shifted due to plant competition. The grass species typically dominate in the simulation until shaded out by tree cover. For further details on how the background simulation was conducted, see “Assumptions and Procedures for Simulating the Natural Vegetation Background Scenario for Cropland” at http://www.nrcs.usda.gov/technical/nri/ceap/cropland.html.

Source Loads and Instream Loads

All source loads are introduced into SWAT at the outlet of each watershed (8-digit hydrologic unit code [HUC]). Flows and source loads from upstream watersheds are routed through each downstream watershed, including reservoirs when present. [23]

A sediment delivery ratio was used to account for deposition in ditches, floodplains, and tributary stream channels during transit from the edge of the field to the outlet. The sediment delivery ratio used in this study is a function of the ratio of the time of concentration for the HRU (land uses other than cultivated cropland) or field (cultivated cropland) to the time of concentration for the watershed (8-digit HUC). The time of concentration for the watershed is the time from when a surface water runoff event occurs at the most distant point in the watershed to the time the surface water runoff reaches the outlet of the watershed. It is calculated by summing the overland flow time (the time it takes for flow from the remotest point in the watershed to reach the channel) and the channel flow time (the time it takes for flow in the upstream channels to reach the outlet). The time of concentration for the field is derived from APEX. The time of concentration for the HRU is derived from characteristics of the watershed, the HRU, and the proportion of total acres represented by the HRU. Consequently, each cultivated cropland sample point has a unique delivery ratio within each watershed, as does each HRU.[24]

The sediment delivery ratio in addition to an enrichment ratio was used to simulate organic nitrogen, organic phosphorus, and sediment-attached pesticide transport in ditches, floodplains, and tributary stream channels during transit from the edge of the field to the outlet. The enrichment ratio was defined as the organic nitrogen, organic phosphorus, and sediment attached pesticide concentration from the edge of field divided by the concentration at the watershed outlet. As sediment is transported from the edge of field to the watershed outlet, coarse sediments are deposited first while more of the fine sediment that hold organic particles remain in suspension, thus enriching the organic concentrations delivered to the watershed outlet.

A separate delivery ratio is used to simulate the transport of nitrate nitrogen, soluble phosphorus, and soluble pesticides. In general, the proportion of soluble nutrients and pesticides delivered to rivers and streams is higher than the proportion attached to sediments because they are not subject to sediment deposition.

For reporting, edge-of-field loads and source loads were aggregated over the 8-digit HUCs to the four subregions in the region (4-digit HUCs). Figure 81 shows the location of each subregion and the 8-digit HUCs included in each. For the Susquehanna River and the Potomac River (8-digit HUC groups I and III), instream loads represent the loads at the outlet of the subregion. For the Upper Chesapeake (8-digit HUC group II), the instream loads represent sum of the loads at the outlets of 8-digit HUCs draining to into Bay in subregion 0206. For the Lower Chesapeake (8-digit HUC groups IV), instream loads represent the sum of the loads at the outlets of Rappahannock, York and James Rivers in subregion, 0208. For the Lower Chesapeake (8-digit HUC group V), instream loads represent the load at the outlet of the Lower Eastern 8-digit HUC (0208109).

There are four points in the modeling process at which source loads or instream loads are assessed, shown in the schematic in figure 82 for sediment.

1. Edge-of-field loads from cultivated cropland—aggregated APEX model output as reported in the previous chapter. (Edge-of-field loads for the Chesapeake Bay watershed differ slightly from those reported in the previous chapter because two 8-digit HUCS that drain to the Atlantic Ocean were excluded and loads from land in long-term conserving cover were included.)

2. Delivery to the watershed outlet from cultivated cropland—aggregated edge-of-field loads after application of delivery ratios. Loadings delivered to streams and rivers differ from the amount leaving the field because of losses during transport from the field to the stream. Delivery ratios are used to make this adjustment.

3. Delivery to the watershed outlet from land uses other than cultivated cropland as simulated by SWAT, after application of delivery ratios. Point sources are included.

4. Loadings in the stream or river at a given point. Instream loads include loadings delivered to the watershed outlet from all sources as well as loads delivered from upstream watersheds, after accounting for channel and reservoir processes.

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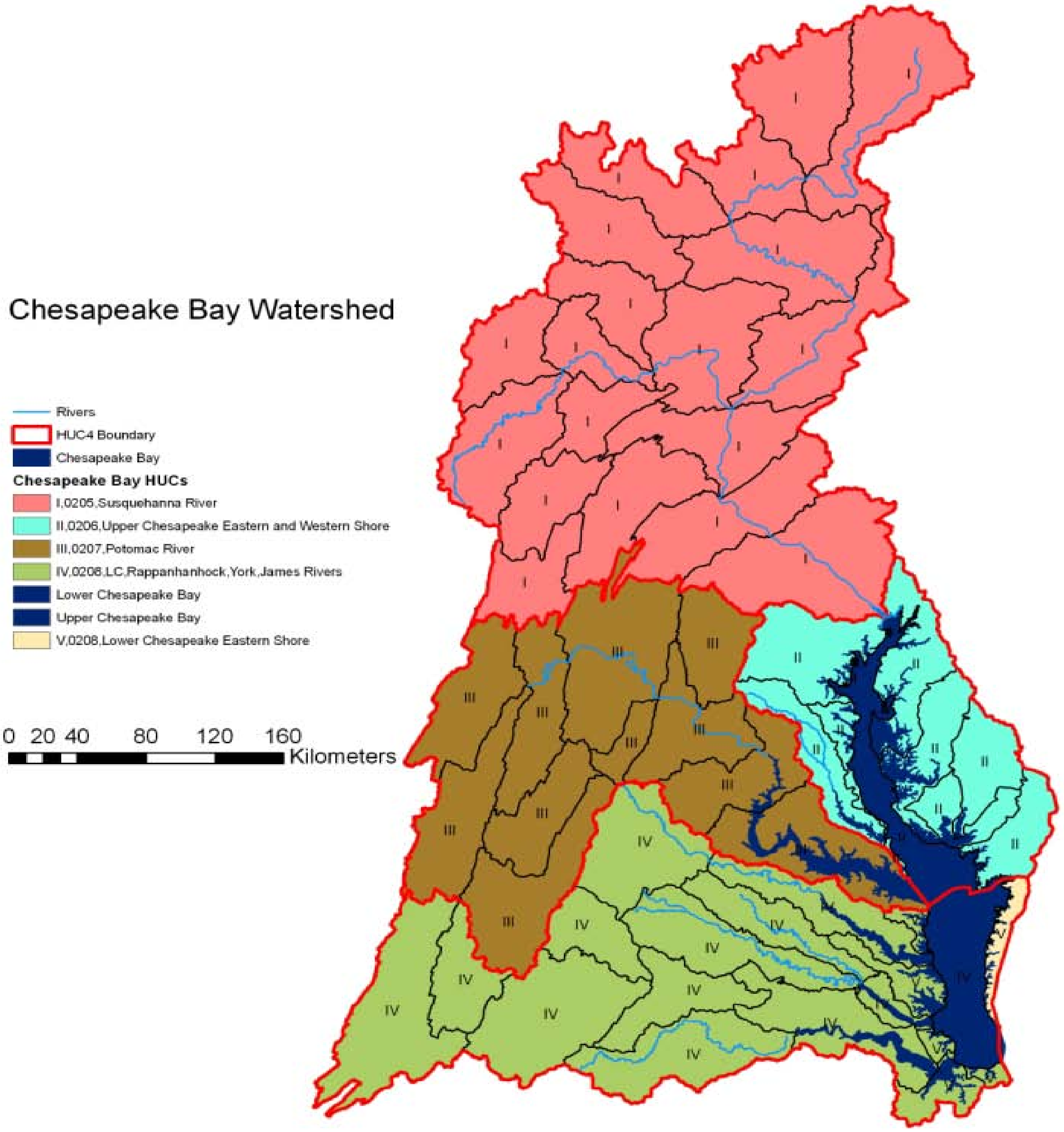
[23] For a complete documentation of HUMUS/SWAT as it was used in this study, see "The HUMUS/SWAT National Water Quality Modeling System" at http://www.nrcs.usda.gov/technical/nri/ceap/Cropland.html.

[24] For a complete documentation of delivery ratios used for the Chesapeake Bay region, see "Delivery Ratios Used in CEAP Cropland Modeling" at http://www.nrcs.usda.gov/technical/nri/ceap/cropland.html.

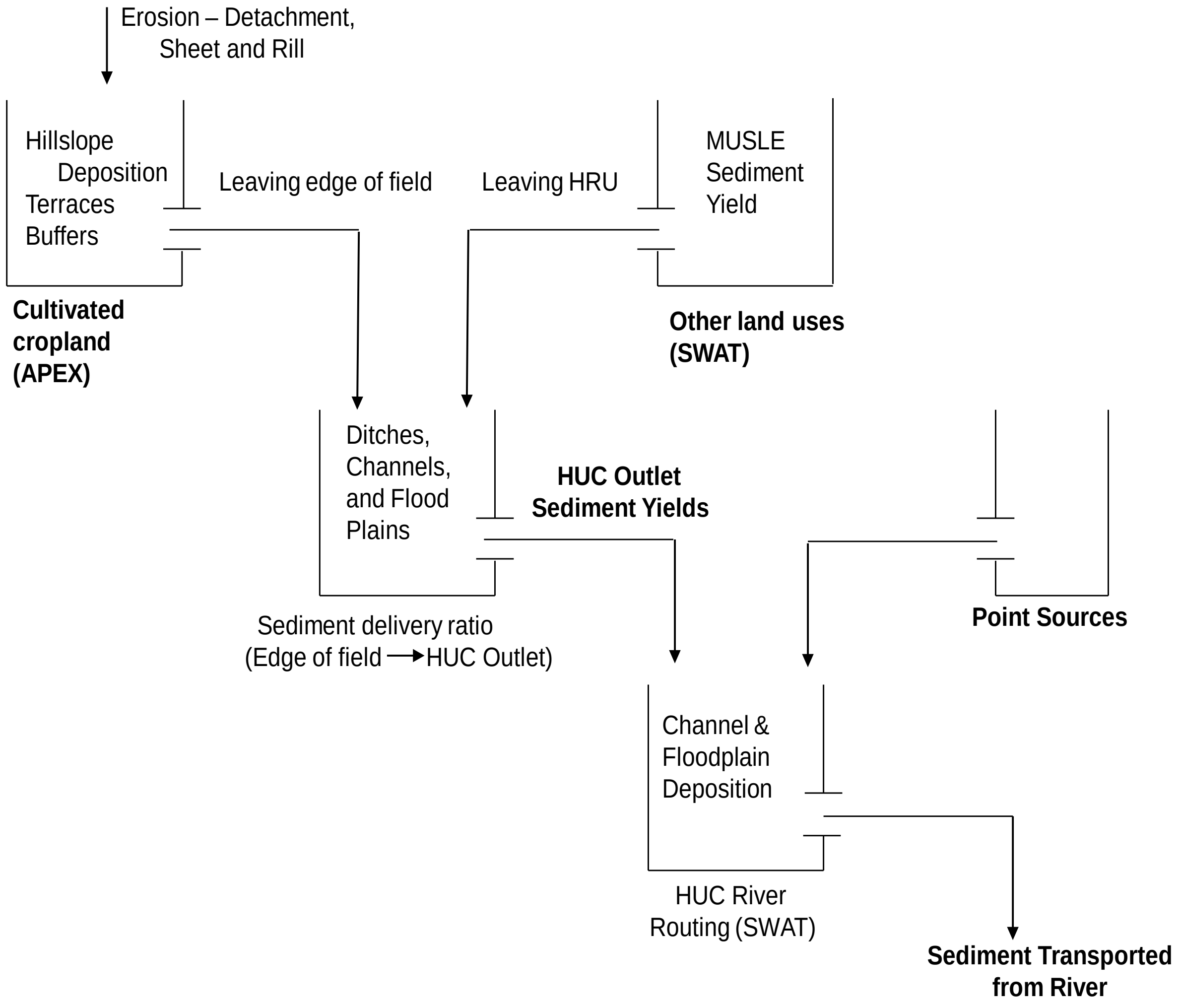
Figure 81. Subregions and 8-digit HUC groups used for reporting of source loads and instream loads for the Chesapeake Bay watershed



Terminology Used in this Report: Chesapeake Bay *Watershed* versus Chesapeake Bay *Region*

Estimates presented in this chapter exclude two 8-digit watersheds in the Upper Chesapeake Bay subregion that drain to the Atlantic Ocean (8-digit HUCs 02060010 and 02080110). The area *excluding* these two subregions is referred to as the Chesapeake Bay *watershed.* However,tables and figures elsewhere in the report *include* the cropped acres in these two 8-digit HUCs; the area that *includes* these two watersheds is referred to as the Chesapeake Bay *region.*

Figure 82. Schematic of sediment sources and delivery as modeled with HUMUS/SWAT for the Chesapeake Bay watershed



Conservation Practice Effects on Water Quality

HUMUS/SWAT accounts for the transport of water, sediment, pesticides, and nutrients from the land to receiving streams and routes the flow downstream to the next watershed and ultimately to estuaries and oceans. Not all of the sediment, nutrients, and pesticides that leave farm fields is delivered to streams and rivers. Some material is bound up permanently in various parts of the landscape during transport. In addition, instream degradation processes and streambed deposition and accumulation remove or trap a portion of the sediment, nutrients, and pesticides after delivery to streams and rivers.

The results from the onsite APEX model simulations for cultivated cropland, including land in long-term conserving cover, were integrated into HUMUS/SWAT to assess the effects of conservation practices on instream loads of sediment, nitrogen, phosphorus, and atrazine. The effects of conservation practices on water quality were assessed by comparing HUMUS/SWAT model simulation results for the baseline conservation condition to simulation results for the no-practice scenario. For each scenario, only the conditions for cultivated cropland were changed, as described previously. All other aspects of the simulations—including sediment and nutrient loads from point sources and land uses other than cultivated cropland—remained the same.

Land Use in the Chesapeake Bay Watershed

The USGS National Land-Cover Database for 2001 (Homer et al. 2007) was the principle source of acreage for HUMUS/SWAT modeling. The 2003 National Resources Inventory (USDA-NRCS 2007) was used to adjust NLCD cropland acreage estimates to include acres in Conservation Reserve Program General Signups, used here to represent cropland currently in long-term conserving cover. Consequently, cultivated cropland acres used to simulate the water quality effects of conservation practices differ slightly from the cropped acres reported in the previous chapters, which were estimated on the basis of the CEAP Cropland sample. In addition, estimates presented in this chapter on off-site water quality exclude two 8-digit watersheds in the Upper Chesapeake Bay subregion that drain to the Atlantic Ocean (8-digit HUCs 02060010 and 02080110) and include land in long-term conserving cover with cultivated cropland.

Estimates of the acreage by land use used to estimate the effects of conservation practices in this chapter are presented in table 38 and figure 83.

Table 38. Land use in the Chesapeake Bay watershed

Sub-region code	Subregion name	Cultivated cropland (acres)*	Hay land not in rotation with crops (acres)	Pasture and grazing land not in rotation with crops (acres)	Urban land (acres)	Forest and other (acres)**	Total land (acres)***
0205	Susquehanna River	2,007,380	1,314,114	1,519,448	1,314,783	11,230,468	17,386,193
0206	Upper Chesapeake Bay	1,218,106	49,817	812,045	526,715	2,310,880	4,917,564
0207	Potomac River	611,355	670,212	1,565,170	1,021,360	5,385,808	9,253,905
0208	Lower Chesapeake Bay	553,641	451,427	1,381,713	734,820	7,307,893	10,429,494
	Total	4,390,482	2,485,571	5,278,375	3,597,679	26,235,048	41,987,155

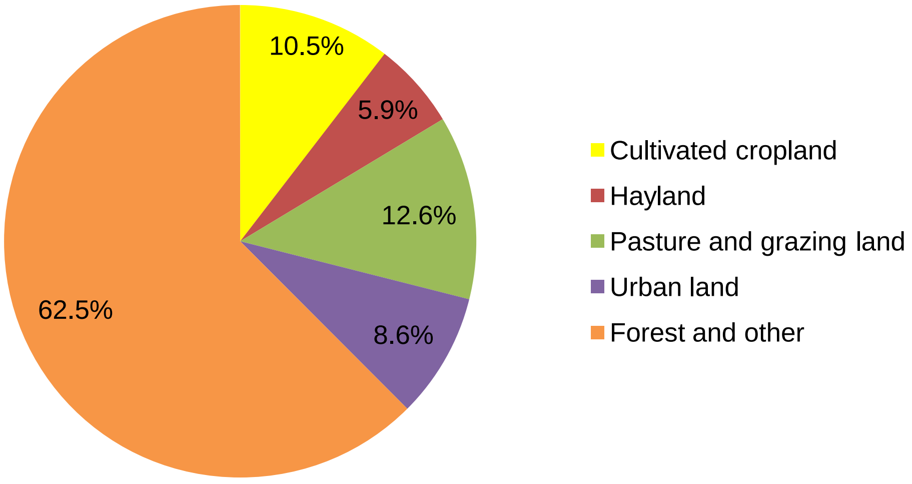
* Acres of cultivated cropland include land in long-term conserving cover as well as hay land and pastureland in rotation with crops.

** Includes forests (all types), wetlands, range brush, horticulture, and barren land.

*** Exclusive of water.

Note: Estimates in this table differ from estimates for the Chesapeake Bay Region by excluding the two 8-digit HUCs draining into the Atlantic Ocean. Estimates were obtained from HUMUS databases on land use, and thus cultivated cropland estimates do not exactly match the acreage estimates obtained from the NRI-CEAP sample.

Figure 83. Percent acres for land use/cover types in the Chesapeake Bay watershed (exclusive of water)



Sediment

Model simulation results show that of the 5.5 million tons of sediment exported from farm fields in the Chesapeake Bay watershed (table 39), about 2 million tons are delivered to rivers and streams each year (table 40), on average, under conditions represented by the baseline conservation condition, which includes farming activities and conservation practices in use during the period 2003 to 2006. Most (about 73 percent) of the sediment from cultivated cropland originates in the Susquehanna River subregion. Sediment delivered to rivers and streams from cultivated cropland represents about 22 percent of the total sediment load delivered from all sources (table 41, figure 84). Runoff from urban nonpoint sources represents about 40 percent of the total load delivered to streams and rivers.

Instream loads—the amount of sediment delivered from all sources to the Bay after accounting for instream deposition and transport processes—totals about 6.8 million tons, averaged over the 47 years of weather as simulated in the model (table 42, figure 85). Overall, about 7 percent of these instream loads delivered to the Bay are attributable to cultivated cropland sources.

Loads from all sources delivered to the Bay were greatest for the Potomac River and the Lower Chesapeake Bay (table 42, figure 85), in part because of their close proximity to the Bay, which reduces opportunities for deposition during transport. Reservoirs in the Susquehanna River basin trap much of the sediment from cultivated cropland in that subregion, preventing it from being transported to the Bay. Although the Susquehanna River subregion delivers more sediment to rivers and streams compared to the Potomac River (tables 40 and 41), the instream sediment load reported at the outlet of Susquehanna River (subregion 0205) is less than the instream load for the Potomac River (subregion 0206) because the Conowingo Reservoir, located just above the outlet of the Susquehanna River, traps a significant portion of the sediment from this subregion (table 42).

Sediment loads delivered to streams and rivers would have been much larger if soil erosion control practices were not in use. Model simulations indicate that conservation practices have reduced the delivery of sediment from fields to rivers and streams by about 57 percent (table 40), on average, and reduced delivery of sediment to the Bay by about 10 percent (table 42, figure 85. Without conservation practices, the total sediment delivered to the Bay would be larger by 747,000 tons (table 42) per year. The Upper Chesapeake subregion has the highest percent reduction in instream loads delivered to the Bay due to conservation practices—24 percent. This subregion also has the highest proportion of instream sediment loads attributed to cultivated cropland sources (15 percent).

Figure 84. Percentage by source of average annual sediment loads delivered to rivers and streams in the Chesapeake Bay watershed

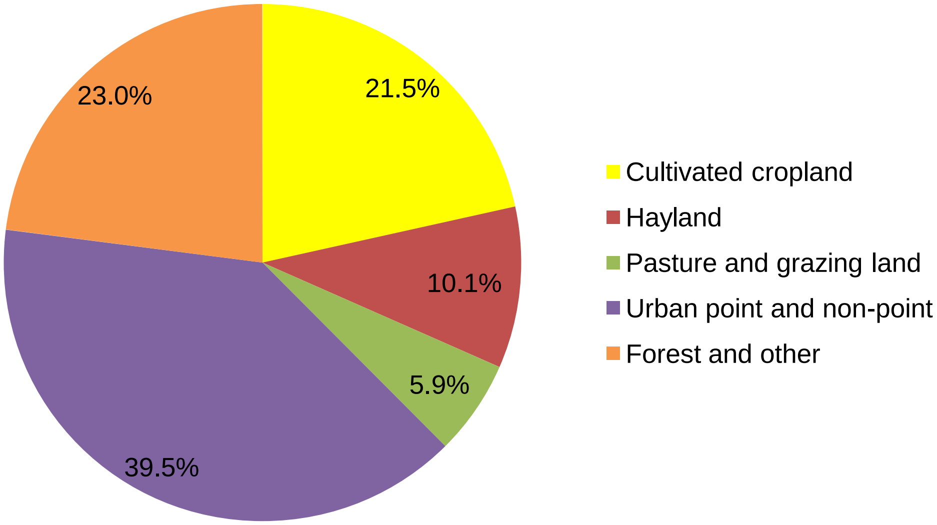


Table 39. Average annual sediment loads ***delivered to edge of field*** (APEX model output) from cultivated cropland for the four subregions in the Chesapeake Bay watershed

			Baseline conservation condition				Reductions in loads due to conservation practices	
8-digit HUC group*	**Sub-region code**	**Subregion name**	**Amount (1,000 tons)**	**Percent of basin total**	**Tons delivered per cropland acre**	**No-practice Scenario (1,000 tons)**	**Reduction (1,000 tons)**	**Percent**
I	0205	Susquehanna River	4,065	74	2.03	8,558	4,493	52
II	0206	Upper Chesapeake**	561	10	0.46	1,741	1,180	68
III	0207	Potomac River	535	10	0.87	1,518	983	65
IV + V	0208	Lower Chesapeake**	318	6	0.57	837	519	62
		Total	5,479	100	1.25	12,653	7,175	57

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Loads represent both cropped acres and land in long-term conserving cover. Some columns do not add to totals because of rounding.

*See figure 81.

**Excludes watersheds that drain into the Atlantic Ocean (8-digit HUCs 02060010 and 02080110).

Table 40 Average annual sediment loads ***delivered to watershed outlets*** (8-digit HUCs) ***from cultivated cropland*** for the four subregions in the Chesapeake Bay watershed

			Baseline conservation condition				Reductions in loads due to conservation practices	
8-digit HUC group*	**Sub-region code**	**Subregion name**	**Amount (1,000 tons)**	**Percent of basin total**	**Tons delivered per cropland acre**	**No-practice Scenario (1,000 tons)**	**Reduction (1,000 tons)**	**Percent**
I	0205	Susquehanna River	1,429	73	0.71	3,042	1,613	53
II	0206	Upper Chesapeake**	218	11	0.18	685	467	68
III	0207	Potomac River	196	10	0.32	571	375	66
IV + V	0208	Lower Chesapeake**	127	6	0.23	336	209	62
		Total	1,970	100	0.45	4,634	2,664	57

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. The differences between loadings in this table and table 39 are due to the application of delivery ratios, which were used to simulate delivery of sediment from the edge of the field to the watershed outlet (8-digit HUC). Some columns do not add to totals because of rounding.

*See figure 81.

**Excludes watersheds that drain into the Atlantic Ocean (8-digit HUCs 02060010 and 02080110).

Table 41. Average annual sediment loads ***delivered to watershed outlets*** (8-digit HUCs***) from all sources*** for the four subregions in the Chesapeake Bay watershed

8-digit HUC group	Sub-region code	Subregion name	All sources	Cultivated cropland*	Hayland	Pasture and grazing land	Urban		Forest and other***
							Non-point sources**	Point sources	
						Amount (1,000 tons)			
I	0205	Susquehanna River	4,246	1,429	708	139	1,274	0	696
II	0206	Upper Chesapeake****	1,119	218	7	79	473	0	342
III	0207	Potomac River	2,010	196	139	147	1,083	0	445
IV + V	0208	Lower Chesapeake****	1,780	127	69	178	787	0	619
		Total	9,155	1,970	924	543	3,617	0	2,102
						Percent of all sources			
I	0205	Susquehanna River	100	34	17	3	30	0	16
II	0206	Upper Chesapeake****	100	19	1	7	42	0	31
III	0207	Potomac River	100	10	7	7	54	0	22
IV + V	0208	Lower Chesapeake****	100	7	4	10	44	0	35
		Total	100	22	10	6	40	0	23

* Includes land in long-term conserving cover, excludes horticulture.

** Includes construction sources and urban land runoff.

*** Includes forests (all types), wetlands, range brush, horticulture, and barren land.

****Excludes watersheds that drain into the Atlantic Ocean (8-digit HUCs 02060010 and 02080110).

Table 42. Average annual ***instream sediment loads*** (all sources) delivered to the Chesapeake Bay

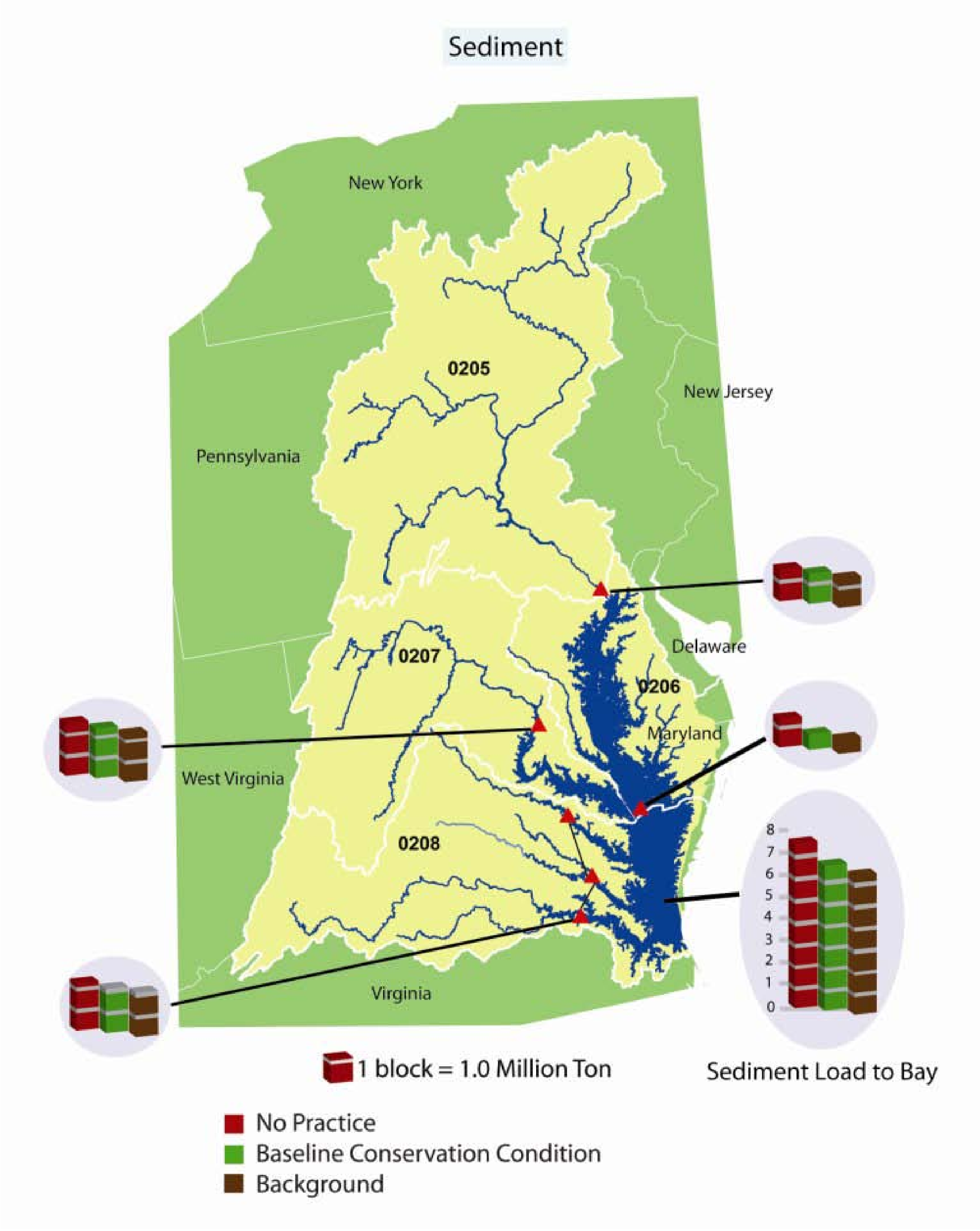
Subregion name	Sub-region code	8-digit HUC group*	Baseline conservation condition			No-practice scenario (1,000 tons)	Reductions in loads due to conservation practices	
			Load from all sources (1,000 tons)	Background sources** (1,000 tons)	Percent of load attributed to cultivated cropland sources		Reduction (1,000 tons)	Percent
Upper Chesapeake Bay								
Susquehanna River	0205	I	1,427	1,295	9	1,518	92	6
Upper Chesapeake	0206	II	934	795	15	1,235	301	24
Potomac River	0207	III	2,364	2,256	5	2,600	236	9
Sub-total			4,725	4,346	8	5,353	628	12
Lower Chesapeake Bay								
Rappahannock, York, and James Rivers	0208	IV	2,023	1,962	3	2,137	114	5
Eastern Shore	0208	V	35	31	13	40	4.3	11
Sub-total			2,058	1,993	3	2,176	118	5
Total			6,783	6,339	7	7,529	747	10

*See figure 81.

****** "Background sources" represent loadings that would be expected if no acres in the watershed were cultivated. These estimates were derived by running an additional scenario that simulated a grass and tree mix cover without any tillage or addition of nutrients or pesticides for all cultivated cropland acres in the watershed.

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Some columns do not add to totals because of rounding.

Figure 85. Estimates of average annual instream sediment loads for the baseline conservation condition compared to the no-practice scenario for subregions in the Chesapeake Bay watershed*



* Instream sediment loads delivered to the Chesapeake Bay (all sources) are shown for each of the four subregions, corresponding to estimates presented in table 42. The total sediment load delivered to the Chesapeake Bay from all areas is shown in the bar chart in the lower right hand corner, labeled "Sediment load to Bay."

Note: "Background sources" represent loads that would be expected if no acres in the watershed were cultivated. These estimates were derived by running an additional scenario that simulated a grass and tree mix cover without any tillage or addition of nutrients or pesticides for all cultivated cropland acres in the watershed. "Background" loads include loads from all other land uses—hayland, pastureland, forestland, and urban land—as well as point sources.

Total Nitrogen

Proportionally, total nitrogen loads (all forms) from cultivated cropland are higher than sediment or phosphorus loads. Model simulation results show that about 148 million pounds of nitrogen are lost from farm fields (edge-of-field) through pathways that result in delivery to streams and rivers within the Chesapeake Bay watershed (table 43). Of this, about 102 million pounds are delivered into rivers and streams each year, on average, under conditions represented by the baseline conservation condition (table 44), which include farming activities and conservation practices in use during the period 2003 to 2006. The majority (about 58 percent) of the nitrogen from cultivated cropland originates in the Susquehanna River subregion, as is the case for sediment and phosphorus. Nitrogen delivered to rivers and streams from cultivated cropland represents about 31 percent of the total nitrogen load delivered from all sources (table 45, fig. 86). Runoff from urban land, including point sources, delivers somewhat more nitrogen—about 37.7 percent of the total load delivered to streams and rivers.

Instream loads—the amount of nitrogen delivered to the Bay after accounting for denitrification, deposition, and other instream transport processes—totals about 308 million pounds from all sources, averaged over the 47 years of weather as simulated in the model (table 46, fig. 87). Overall, about 29 percent of these instream loads delivered to the Bay are attributable to cultivated cropland sources. Instream loads from all sources delivered to the Bay were greatest for the Susquehanna River subregion (table 46, fig. 87). The Susquehanna River also has the highest proportion of instream loads attributable to cultivated cropland—41 percent.

Conservation practices in use throughout the watershed have reduced nitrogen loads, but not as dramatically as sediment loads, as discussed in the previous chapter. Model simulations indicate that conservation practices have reduced the delivery of nitrogen from fields to rivers and streams by about 36 percent (table 44), on average, and reduced delivery of nitrogen to the Bay by about 14 percent (table 46, fig. 87). Nitrogen loads delivered to the Bay would have been larger by about 52 million pounds per year if conservation practices were not in use (table 46). Over half of this reduction is in the Susquehanna River subregion, where total nitrogen instream loads have been reduced by 19 percent due to the use of conservation practices.

Figure 86. Percentage by source of average annual nitrogen loads delivered to rivers and streams in the Chesapeake Bay watershed

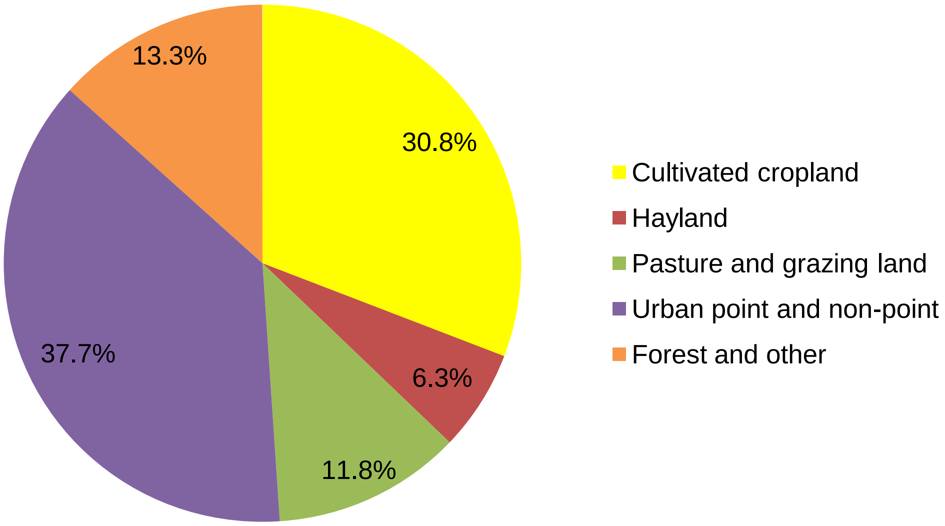


Table 43. Average annual nitrogen source loads ***delivered to edge of field*** (APEX model output) from cultivated cropland for the four subregions in the Chesapeake Bay watershed

			Baseline conservation condition				Reductions in loads due to conservation practices	
8-digit HUC group*	**Sub-region code**	**Subregion name**	**Amount (1,000 pounds)**	**Percent of basin total**	**Pounds delivered per cropland acre**	**No-practice Scenario (1,000 pounds)**	**Reduction (1,000 pounds)**	**Percent**
I	0205	Susquehanna River	87,691	59	43.68	138,060	50,369	36
II	0206	Upper Chesapeake**	31,214	21	25.63	48,338	17,124	35
III	0207	Potomac River	18,417	12	30.12	29,799	11,382	38
IV + V	0208	Lower Chesapeake**	10,411	7	18.80	16,461	6,050	37
		Total	147,733	100	33.65	232,658	84,925	37

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Loads represent both cropped acres and land in long-term conserving cover. Some columns do not add to totals because of rounding.

*See figure 81.

**Excludes watersheds that drain into the Atlantic Ocean (8-digit HUCs 02060010 and 02080110).

Table 44. Average annual nitrogen source loads ***delivered to watershed outlets*** (8-digit HUCs) from cultivated cropland for the four subregions in the Chesapeake Bay watershed

			Baseline conservation condition				Reductions in loads due to conservation practices	
8-digit HUC group*	**Sub-region code**	**Subregion name**	**Amount (1,000 pounds)**	**Percent of basin total**	**Pounds delivered per cropland acre**	**No-practice Scenario (1,000 pounds)**	**Reduction (1,000 pounds)**	**Percent**
I	0205	Susquehanna River	58,939	58	29.4	92,134	33,195	36
II	0206	Upper Chesapeake**	22,592	22	18.5	34,731	12,139	35
III	0207	Potomac River	12,761	13	20.9	20,523	7,762	38
IV + V	0208	Lower Chesapeake**	7,319	7	13.2	11,765	4,446	38
		Total	101,611	100	23.1	159,153	57,542	36

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. The differences between loadings in this table and table 43 are due to the application of delivery ratios, which were used to simulate delivery of nitrogen from the edge of the field to the watershed outlet (8-digit HUC). Some columns do not add to totals because of rounding.

*See figure 81.

**Excludes watersheds that drain into the Atlantic Ocean (8-digit HUCs 02060010 and 02080110).

Table 45. Average annual nitrogen loads ***delivered to watershed outlets*** (8-digit HUCs***) from all sources*** for the four subregions in the Chesapeake Bay watershed

8-digit HUC group	Sub-region code	Subregion name	All sources	Cultivated cropland*	Hayland	Pasture and grazing land	Urban Non-point sources**	Urban Point sources	Forest and other***
						Amount (1,000 pounds)			
I	0205	Susquehanna River	140,802	58,939	13,891	15,822	9,335	24,760	18,046
II	0206	Upper Chesapeake****	53,112	22,592	543	4,111	5,047	16,419	4,397
III	0207	Potomac River	78,256	12,761	4,457	12,601	9,743	28,250	10,441
IV + V	0208	Lower Chesapeake****	57,326	7,319	1,856	6,302	6,840	23,916	11,091
		Total	329,496	101,611	20,747	38,836	30,965	93,345	43,974
						Percent of all sources			
I	0205	Susquehanna River	100	42	10	11	7	18	13
II	0206	Upper Chesapeake****	100	43	1	8	10	31	8
III	0207	Potomac River	100	16	6	16	12	36	13
IV + V	0208	Lower Chesapeake****	100	13	3	11	12	42	19
		Total	100	31	6	12	9	28	13

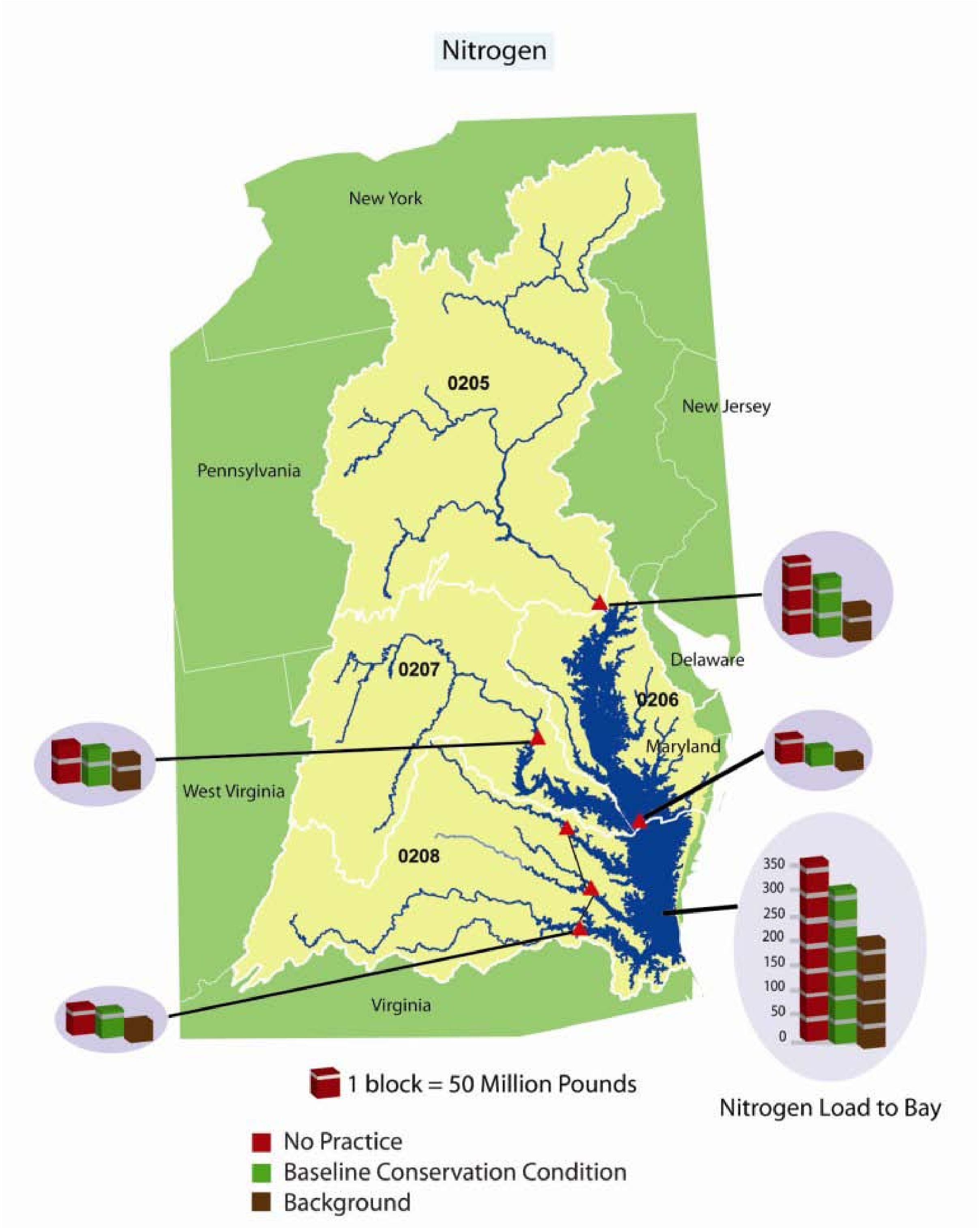
* Includes land in long-term conserving cover, excludes horticulture.
** Includes construction sources and urban land runoff.
*** Includes forests (all types), wetlands, range brush, horticulture, and barren land.
****Excludes watersheds that drain into the Atlantic Ocean (8-digit HUCs 02060010 and 02080110).

Table 46. Average annual ***instream total nitrogen loads*** (all sources) delivered to the Chesapeake Bay

Subregion name	Sub-region code	8-digit HUC group*	Baseline conservation condition Load from all sources (1,000 pounds)	Baseline conservation condition Background sources** (1,000 pounds)	Baseline conservation condition Percent of load attributed to cultivated cropland sources	No-practice scenario (1,000 pounds)	Reductions in loads due to conservation practices Reduction (1,000 pounds)	Reductions in loads due to conservation practices Percent
Upper Chesapeake Bay								
Susquehanna River	0205	I	125,260	73,613	41	155,120	29,859	19
Upper Chesapeake	0206	II	46,634	29,343	37	56,840	10,206	18
Potomac River	0207	III	80,365	67,454	16	88,303	7,938	9
Sub-total			252,259	170,410	32	300,263	48,003	16
Lower Chesapeake Bay								
Rappahannock, York, and James Rivers	0208	IV	54,605	48,505	11	58,396	3,791	6
Eastern Shore	0208	V	1,372	858	37	1,765	393	22
Sub-total			55,977	49,363	12	60,161	4,184	7
Total			308,236	219,773	29	360,424	52,187	14

*See figure 81.
****** "Background sources" represent loadings that would be expected if no acres in the watershed were cultivated. These estimates were derived by running an additional scenario that simulated a grass and tree mix cover without any tillage or addition of nutrients or pesticides for all cultivated cropland acres in the watershed.
Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Some columns do not add to totals because of rounding.

Figure 87. Estimates of average annual instream nitrogen loads for the baseline conservation condition compared to the no-practice scenario for subregions in the Chesapeake Bay watershed*



* Instream nitrogen loads delivered to the Chesapeake Bay (all sources) are shown for each of the four subregions, corresponding to estimates presented in table 46. The total sediment load delivered to the Chesapeake Bay from all areas is shown in the bar chart in the lower right hand corner, labeled "Nitrogen load to Bay."

Note: "Background sources" represent loads that would be expected if no acres in the watershed were cultivated. These estimates were derived by running an additional scenario that simulated a grass and tree mix cover without any tillage or addition of nutrients or pesticides for all cultivated cropland acres in the watershed. "Background" loads include loads from all other land uses—hayland, pastureland, forestland, and urban land—as well as point sources.

Total Phosphorus

Model simulation results show that about 16 million pounds of phosphorus are lost from farm fields (edge-of-field) through pathways that result in delivery to streams and rivers within the Chesapeake Bay watershed (table 47). Of this, about 6.4 million pounds is delivered into rivers and streams each year, on average, under conditions represented by the baseline conservation condition (table 48), which include farming activities and conservation practices in use during the period 2003 to 2006. The majority of the phosphorus from cultivated cropland originates in the Susquehanna River subregion. Phosphorus delivered to rivers and streams from cultivated cropland represents about 28 percent of the total phosphorus load delivered from all sources (table 49, fig. 88). The dominant source of phosphorus delivered into streams and rivers is runoff from urban land and point sources—about 50 percent of the total load delivered to streams and rivers.

Instream loads—the amount of phosphorus delivered from all sources to the Bay after accounting for deposition and other instream transport processes—totals about 14.8 million pounds, averaged over the 47 years of weather as simulated in the model (table 50, fig. 89). Overall, about 23 percent of these instream loads delivered to the Bay are attributable to cultivated cropland sources.

Instream loads from all sources delivered to the Bay were greatest for the Lower Chesapeake subregion (table 50, fig. 89), mostly from sources other than cultivated cropland. The Susquehanna River and the Upper Chesapeake subregions have the highest proportion of instream loads attributable to cultivated cropland—34 and 35 percent, respectively (table 50).

Phosphorus loads delivered to streams and rivers would have been much larger if soil erosion control practices were not in use. Model simulations indicate that conservation practices have reduced the delivery of phosphorus from fields to rivers and streams by about 39 percent (table 48), on average, and reduced delivery of phosphorus to the Bay by about 14 percent (table 50, fig. 89). Phosphorus loads delivered to the Bay would have been larger by about 2.4 million pounds per year if conservation practices were not in use (table 50). The Upper Chesapeake subregion has the highest percent reduction in instream loads delivered to the Bay due to conservation practices—31 percent.

Figure 88. Percentage by source of average annual phosphorus loads delivered to rivers and streams in the Chesapeake Bay watershed

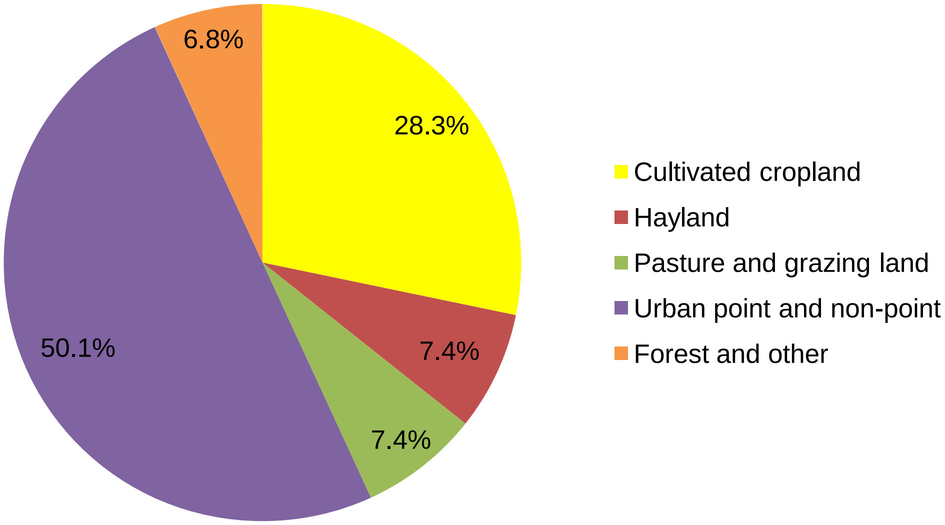


Table 47. Average annual phosphorus source loads ***delivered to edge of field*** (APEX model output) from cultivated cropland for the four subregions in the Chesapeake Bay watershed

			Baseline conservation condition				Reductions in loads due to conservation practices	
8-digit HUC group*	**Sub-region code**	**Subregion name**	**Amount (1,000 pounds)**	**Percent of basin total**	**Pounds delivered per cropland acre**	**No-practice Scenario (1,000 pounds)**	**Reduction (1,000 pounds)**	**Percent**
I	0205	Susquehanna River	9,798	61	4.88	16,188	6,390	39
II	0206	Upper Chesapeake**	2,615	16	2.15	5,737	3,123	54
III	0207	Potomac River	2,612	16	4.27	4,106	1,494	36
IV + V	0208	Lower Chesapeake**	1,157	7	2.09	1,805	647	36
		Total	16,183	100	3.69	27,836	11,653	42

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Loads represent both cropped acres and land in long-term conserving cover. Some columns do not add to totals because of rounding.

*See figure 81.

**Excludes watersheds that drain into the Atlantic Ocean (8-digit HUCs 02060010 and 02080110).

Table 48. Average annual phosphorus source loads ***delivered to watershed outlets*** (8-digit HUCs) from cultivated cropland for the four subregions in the Chesapeake Bay watershed

			Baseline conservation condition				Reductions in loads due to conservation practices	
8-digit HUC group*	**Sub-region code**	**Subregion name**	**Amount (1,000 pounds)**	**Percent of basin total**	**Pounds delivered per cropland acre**	**No-practice Scenario (1,000 pounds)**	**Reduction (1,000 pounds)**	**Percent**
I	0205	Susquehanna River	3,702	58	1.84	5,822	2,120	36
II	0206	Upper Chesapeake**	1,152	18	0.95	2,474	1,322	53
III	0207	Potomac River	1,077	17	1.76	1,558	481	31
IV + V	0208	Lower Chesapeake**	499	8	0.90	753	255	34
		Total	6,430	100	1.46	10,607	4,177	39

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. The differences between loadings in this table and table 47 are due to the application of delivery ratios, which were used to simulate delivery of phosphorus from the edge of the field to the watershed outlet (8-digit HUC). Some columns do not add to totals because of rounding.

*See figure 81.

**Excludes watersheds that drain into the Atlantic Ocean (8-digit HUCs 02060010 and 02080110).

Table 49. Average annual phosphorus loads ***delivered to watershed outlets*** (8-digit HUCs***) from all sources*** for the four subregions in the Chesapeake Bay watershed

8-digit HUC group	Sub-region code	Subregion name	All sources	Cultivated cropland*	Hayland	Pasture and grazing land	Urban		Forest and other***
							Non-point sources**	Point sources	
						Amount (1,000 pounds)			
I	0205	Susquehanna River	10,599	3,702	1,316	554	580	3,885	562
II	0206	Upper Chesapeake****	2,726	1,152	15	132	198	1,015	214
III	0207	Potomac River	4,717	1,077	270	602	531	1,895	341
IV + V	0208	Lower Chesapeake****	4,714	499	87	406	417	2,870	436
		Total	22,756	6,430	1,689	1,693	1,726	9,664	1,552
						Percent of all sources			
I	0205	Susquehanna River	100	35	12	5	5	37	5
II	0206	Upper Chesapeake****	100	42	1	5	7	37	8
III	0207	Potomac River	100	23	6	13	11	40	7
IV + V	0208	Lower Chesapeake****	100	11	2	9	9	61	9
		Total	100	28	7	7	8	42	7

* Includes land in long-term conserving cover, excludes horticulture.

** Includes construction sources and urban land runoff.

*** Includes forests (all types), wetlands, range brush, horticulture, and barren land.

****Excludes watersheds that drain into the Atlantic Ocean (8-digit HUCs 02060010 and 02080110).

Table 50. Average annual ***instream total phosphorus loads*** (all sources) delivered to the Chesapeake Bay

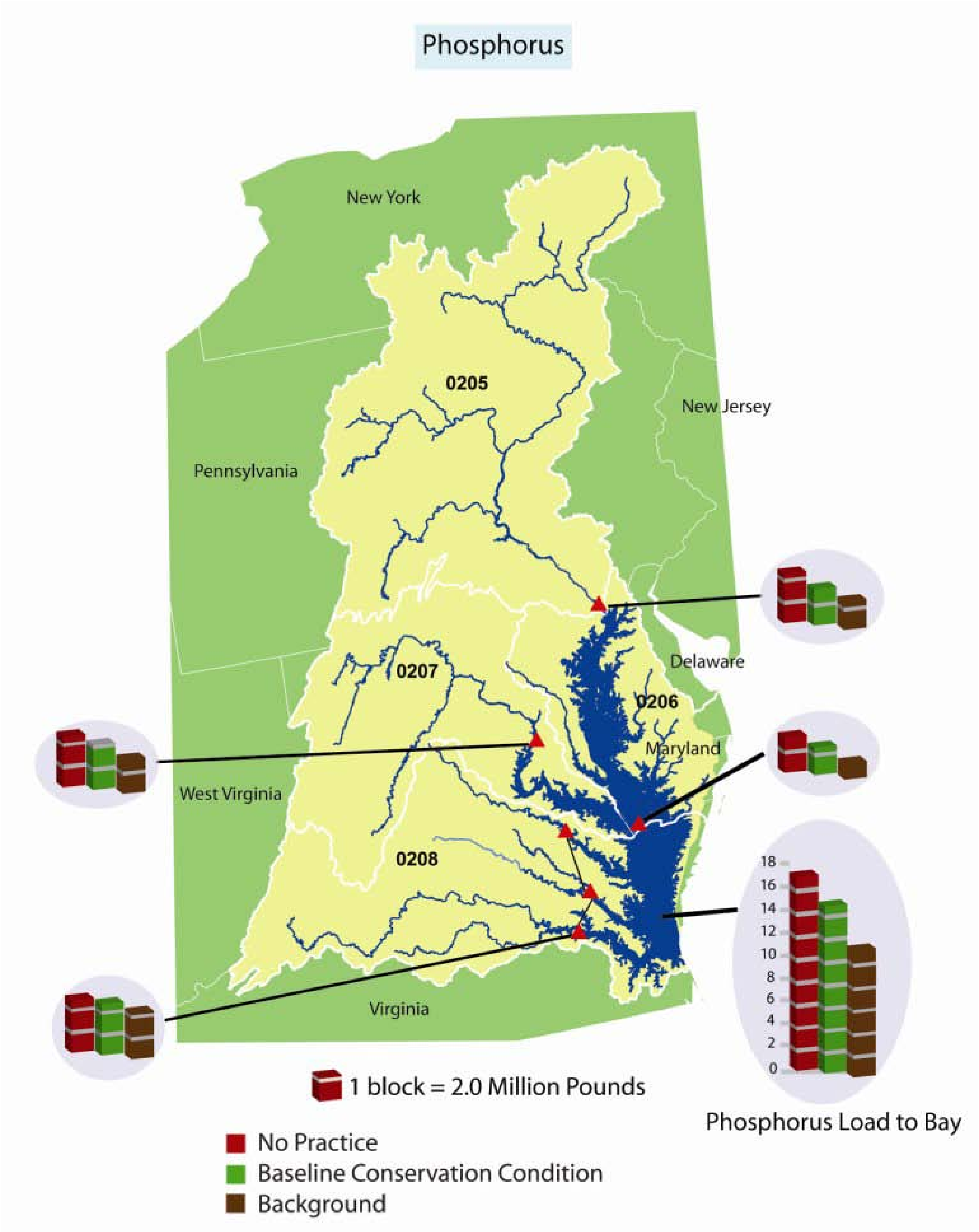
Subregion name	Sub-region code	8-digit HUC group*	Baseline conservation condition			No-practice scenario (1,000 pounds)	Reductions in loads due to conservation practices	
			Load from all sources (1,000 pounds)	Background sources** (1,000 pounds)	Percent of load attributed to cultivated cropland sources		Reduction (1,000 pounds)	Percent
Upper Chesapeake Bay								
Susquehanna River	0205	I	3,815	2,522	34	4,553	738	16
Upper Chesapeake	0206	II	2,362	1,525	35	3,415	1,054	31
Potomac River	0207	III	4,000	3,086	23	4,409	409	9
Sub-total			10,177	7,133	30	12,377	2,200	18
Lower Chesapeake Bay								
Rappahannock, York, and James Rivers	0208	IV	4,544	4,135	9	4,743	198	4
Eastern Shore	0208	V	92	75	19	124	32	26
Sub-total			4,636	4,210	9	4,867	230	5
Total			14,813	11,342	23	17,243	2,430	14

*See figure 81.

****** "Background sources" represent loadings that would be expected if no acres in the watershed were cultivated. These estimates were derived by running an additional scenario that simulated a grass and tree mix cover without any tillage or addition of nutrients or pesticides for all cultivated cropland acres in the watershed.

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Some columns do not add to totals because of rounding.

Figure 89. Estimates of average annual instream phosphorus loads for the baseline conservation condition compared to the no-practice scenario for subregions in the Chesapeake Bay watershed*



* Instream phosphorus loads delivered to the Chesapeake Bay (all sources) are shown for each of the four subregions, corresponding to estimates presented in table 50. The total sediment load delivered to the Chesapeake Bay from all areas is shown in the bar chart in the lower right hand corner, labeled "Phosphorus load to Bay."

Note: "Background sources" represent loads that would be expected if no acres in the watershed were cultivated. These estimates were derived by running an additional scenario that simulated a grass and tree mix cover without any tillage or addition of nutrients or pesticides for all cultivated cropland acres in the watershed. "Background" loads include loads from all other land uses—hayland, pastureland, forestland, and urban land—as well as point sources.

Atrazine

Although the full suite of pesticides were modeled for edge-of-field losses, atrazine was the only pesticide for which in-stream loads were assessed because it was the dominant contributor to mass loss of pesticide residues from farm fields and the primary contributor to environmental risk from pesticides in the region. First registered in the United States in 1959, atrazine is used to control broadleaf and grassy weeds.

Cultivated cropland (primarily corn acres) was the only source for atrazine in the model simulations.

Model simulation results show that nearly 18,000 pounds of atrazine are lost from farm fields (edge-of-field) through pathways that result in delivery to streams and rivers within the Chesapeake Bay watershed (table 51). Of this, about 16,000 pounds is delivered into rivers and streams each year, on average, under conditions represented by the baseline conservation condition (table 52). About half of the atrazine from cultivated cropland originates in the Susquehanna River subregion. Instream loads—the amount of atrazine delivered to the Bay after accounting for degradation and other instream transport processes—totals about 11,590 pounds (table 53, fig. 90).

Conservation practices—including Integrated Pest Management (IPM) techniques and practices—have reduced the delivery of atrazine from fields to rivers and streams by about 21 percent (table 52), on average, and reduced delivery of atrazine to the Bay by about 18 percent (table 53, figure 90). Atrazine loads delivered to the Bay would have been larger by about 2,500 pounds per year if conservation practices were not in use (table 53).

Table 51. Average annual atrazine source loads ***delivered to edge of field*** (APEX model output) from cultivated cropland for the 4 subregions in the Chesapeake Bay watershed

			Baseline conservation condition				Reductions in loads due to conservation practices	
8-digit HUC group*	Sub-region code	Subregion name	Amount (1,000 pounds)	Percent of basin total	Pounds delivered per cropland acre	No-practice Scenario (1,000 pounds)	Reduction (1,000 pounds)	Percent
I	0205	Susquehanna River	8.55	47	0.0043	11.05	2.50	23
II	0206	Upper Chesapeake**	4.68	26	0.0038	6.54	1.86	28
III	0207	Potomac River	3.15	17	0.0052	3.56	0.41	11
IV + V	0208	Lower Chesapeake**	1.98	11	0.0036	2.13	0.16	7
		Total	18.35	100	0.0042	23.28	4.93	21

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Loads represent both cropped acres and land in long-term conserving cover. Some columns do not add to totals because of rounding.

*See figure 81.

**Excludes watersheds that drain into the Atlantic Ocean (8-digit HUCs 02060010 and 02080110).

Table 52. Average annual atrazine source loads ***delivered to watershed outlets*** (8-digit HUCs) from cultivated cropland for the 4 subregions in the Chesapeake Bay watershed

			Baseline conservation condition				Reductions in loads due to conservation practices	
8-digit HUC group*	Sub-region code	Subregion name	Amount (1,000 pounds)	Percent of basin total	Pounds delivered per cropland acre	No-practice Scenario (1,000 pounds)	Reduction (1,000 pounds)	Percent
I	0205	Susquehanna River	7.40	46	0.0037	9.55	2.14	22
II	0206	Upper Chesapeake**	4.26	26	0.0035	5.98	1.73	29
III	0207	Potomac River	2.80	17	0.0046	3.12	0.32	10
IV + V	0208	Lower Chesapeake**	1.72	11	0.0031	1.88	0.16	8
		Total	16.18	100	0.0037	20.53	4.35	21

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. The differences between loadings in this table and table 51 are due to the application of delivery ratios, which were used to simulate delivery of atrazine from the edge of the field to the watershed outlet (8-digit HUC). Some columns do not add to totals because of rounding.

*See figure 81.

**Excludes watersheds that drain into the Atlantic Ocean (8-digit HUCs 02060010 and 02080110).

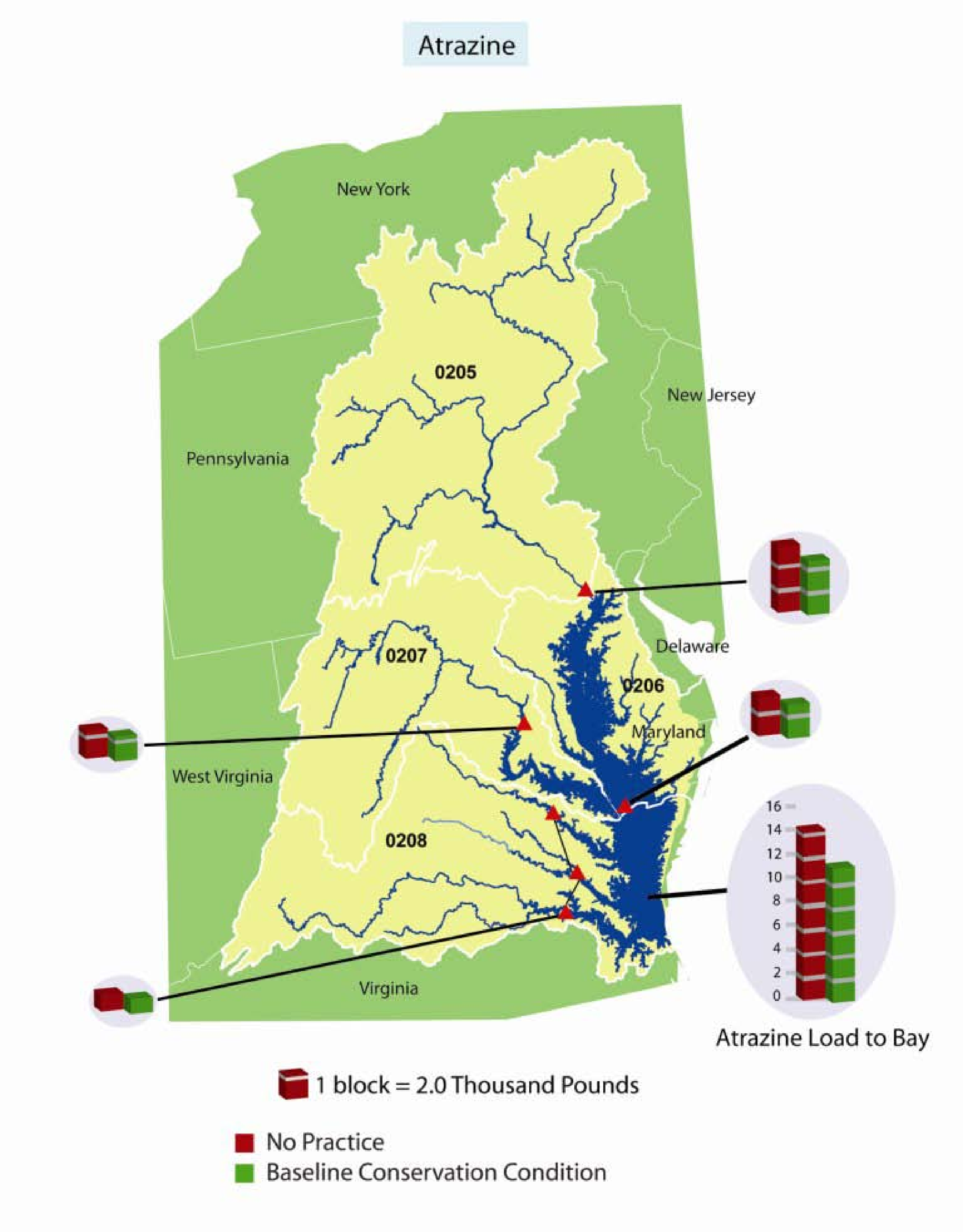
Table 53. Average annual ***instream atrazine loads*** delivered to the Chesapeake Bay

					Reductions in loads due to conservation practices	
Subregion name	Sub-region code	8-digit HUC group*	Baseline conservation condition (1,000 pounds)	No-practice scenario (1,000 pounds)	Reduction (1,000 pounds)	Percent
Upper Chesapeake Bay						
Susquehanna River	0205	I	4.63	5.96	1.33	22
Upper Chesapeake	0206	II	3.05	3.78	0.74	19
Potomac River	0207	III	2.43	2.68	0.26	10
Sub-total			10.10	12.42	2.33	19
Lower Chesapeake Bay						
Rappahannock, York, and James Rivers	0208	IV	1.44	1.59	0.14	9
Eastern Shore	0208	V	0.05	0.08	0.03	33
Sub-total			1.50	1.66	0.17	10
Total			11.59	14.09	2.49	18

*See figure 81.

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Some columns do not add to totals because of rounding.

Figure 90. Estimates of average annual instream atrazine loads for the baseline conservation condition compared to the no-practice scenario for subregions in the Chesapeake Bay watershed*



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* Instream atrazine loads delivered to the Chesapeake Bay (all sources) are shown for each of the four subregions, corresponding to estimates presented in table 53. The total sediment load delivered to the Chesapeake Bay from all areas is shown in the bar chart in the lower right hand corner, labeled "Atrazine load to Bay."

Assessment of Potential Water Quality Gains from Further Conservation Treatment

The field-level model results for the scenarios with additional erosion control practices *and* nutrient management (chapter 6) were used with the HUMUS/SWAT model to determine the potential for further reductions in loads delivered from cultivated cropland to rivers and streams within the watershed and total loads delivered to the Bay (instream loads) with additional conservation treatment.

Percent reductions relative to the current conservation condition were estimated for each of two scenarios (tables 54 through 65)—

1. treatment of the 0.8 million critical under-treated acres (acres with a high need for additional treatment), and
2. treatment of all 3.4 million under-treated acres, including the 0.8 million critical under-treated acres).

The distribution of under-treated acres within the Chesapeake Bay watershed is shown in chapter 5, table 30.

The model simulations not only demonstrate the relative gains that can be expected from different levels of conservation effort but also provide insight into which subregions are the most important in terms of reducing overall loads exported to the Bay. Comparisons of the baseline condition with the estimates of reductions in total loads (all sources) achievable under the two scenarios are shown in figures 91 through 94.

Model simulations showed that if the 0.8 million under-treated acres were fully treated with the appropriate soil erosion control and/or nutrient management practices, loads from cultivated cropland delivered to rivers and streams in the watershed would be reduced by, relative to the baseline conservation condition (tables 55, 58, 61, and 64)—

- 39 percent for sediment,
- 22 percent for nitrogen,
- 24 percent for phosphorus, and
- 7 percent for atrazine.

The largest reductions for all four resource concerns would occur in the Susquehanna River subregion.

Model simulations further showed that if all of the under-treated acres (an additional 2.6 million acres) were fully treated with the appropriate soil erosion control and/or nutrient management practices, loads from cultivated cropland delivered to rivers and streams in the watershed would be reduced, relative to the baseline conservation condition (tables (tables 55, 58, 61, and 64)—

- 84 percent for sediment,
- 52 percent for nitrogen,
- 51 percent for phosphorus, and
- 11 percent for atrazine.

These reductions in loads delivered to rivers and streams would also have a significant impact on the total loads from all sources delivered to the Bay. If all the critical under-treated acres (0.8 million acres) were fully treated with the appropriate soil erosion control and/or nutrient management practices, total loads delivered to the Bay would be reduced, relative to the baseline conservation condition (tables 56, 59, 62, and 65 and figs. 91 through 94)—

- 2 percent for sediment,
- 7 percent for nitrogen,
- 5 percent for phosphorus, and
- 6 percent for atrazine.

If *all* the under-treated acres (2.6 million additional acres) were fully treated with the appropriate soil erosion control and/or nutrient management practices, total loads delivered to the Bay would be reduced, relative to the baseline conservation condition (tables 56, 59, 62, and 65 and through91-94)—

- 6 percent for sediment,
- 15 percent for nitrogen,
- 12 percent for phosphorus, and
- 9 percent for atrazine.

At this level of conservation treatment, sediment loads delivered to the Bay would be very close to the background level, indicating that contributions from cultivated cropland would be negligible. The background scenario represents loads that would be expected if no acres in the watershed were cultivated. For sediment, background loads would total 6.339 million tons (table 56). Total loads delivered from all sources after treating all under-treated acres with appropriate erosion control and nutrient management practices would total 6.378 million tons (table 56), leaving only 39,000 tons originating from cultivated cropland.

Similarly, if all under-treated acres were fully treated, loads delivered to the Bay originating from cultivated cropland would be only about 42 million pounds for nitrogen and 1.6 million pounds for phosphorus (tables 59 and 62).

Table 54. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual **sediment source loads *delivered to edge of field*** (APEX model output) from cultivated cropland for the 4 subregions in the Chesapeake Bay watershed

			Baseline conservation condition	Treatment of 0.8 million critical under-treated acres		Treatment of all 3.4 million under-treated acres	
8-digit HUC group*	**Sub-region code**	**Subregion name**	Average annual load (1,000 tons)	Average annual load (1,000 tons)	Percent reduction	Average annual load (1,000 tons)	Percent reduction
I	0205	Susquehanna River	4,065	2,141	47	441	89
II	0206	Upper Chesapeake**	561	488	13	175	69
III	0207	Potomac River	535	424	21	66	88
IV + V	0208	Lower Chesapeake**	318	228	28	59	82
		Total	5,479	3,281	40	742	86

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Loads represent both cropped acres and land in long-term conserving cover. Some columns do not add to totals because of rounding.

Note: Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

*See figure 81.

**Excludes watersheds that drain into the Atlantic Ocean (8-digit HUCs 02060010 and 02080110).

Table 55. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual **sediment source loads *delivered to watershed outlets*** (8-digit HUCs) from cultivated cropland for the 4 subregions in the Chesapeake Bay watershed

			Baseline conservation condition	Treatment of 0.8 million critical under-treated acres		Treatment of all 3.4 million under-treated acres	
8-digit HUC group*	**Sub-region code**	**Subregion name**	Average annual load (1,000 tons)	Average annual load (1,000 tons)	Percent reduction	Average annual load (1,000 tons)	Percent reduction
I	0205	Susquehanna River	1,429	762	47	181	87
II	0206	Upper Chesapeake**	218	192	12	75	66
III	0207	Potomac River	196	157	20	28	86
IV + V	0208	Lower Chesapeake**	127	93	27	26	79
		Total	1,970	1,204	39	310	84

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. The differences between loadings in this table and table 51 are due to the application of delivery ratios, which were used to simulate delivery of sediment from the edge of the field to the watershed outlet (8-digit HUC). Some columns do not add to totals because of rounding.

Note: Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

*See figure 81.

**Excludes watersheds that drain into the Atlantic Ocean (8-digit HUCs 02060010 and 02080110).

Table 56. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual ***instream sediment loads*** from all sources delivered to the Chesapeake Bay

			Baseline conservation condition		Treatment of 0.8 million critical under-treated acres		Treatment of all 3.4 million under-treated acres	
Subregion name	**Sub-region code**	**8-digit HUC group***	Average annual load from all sources (1,000 tons)	Average annual load from background sources** (1,000 tons)	Average annual load (1,000 tons)	Percent reduction	Average annual load (1,000 tons)	Percent reduction
Upper Chesapeake Bay								
Susquehanna River	0205	I	1,427	1,295	1,369	4	1,294	9
Upper Chesapeake	0206	II	934	795	914	2	836	11
Potomac River	0207	III	2,364	2,256	2,337	1	2,249	5
Sub-total			4,725	4,346	4,620	2	4,379	7
Lower Chesapeake Bay								
Rappahannock, York, and James Rivers	0208	IV	2,023	1,962	2,004	1	1,966	3
Eastern Shore	0208	V	35	31	35	<1	33	7
Sub-total			2,058	1,993	2,039	1	1,999	3
Total			6,783	6,339	6,659	2	6,378	6

*See figure 81.

** “Background sources” represent loads that would be expected if no acres in the watershed were cultivated. These estimates were derived by running an additional scenario that simulated a grass and tree mix cover without any tillage or addition of nutrients or pesticides for all cultivated cropland acres in the watershed. “Background” loads include loads from all other land uses—hayland, pastureland, forestland, and urban land—as well as point sources.

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Some columns do not add to totals because of rounding.

Note: Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

Table 57. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual **nitrogen source loads *delivered to edge of field*** (APEX model output) from cultivated cropland for the 4 subregions in the Chesapeake Bay watershed

			Baseline conservation condition	Treatment of 0.8 million critical under-treated acres		Treatment of all 3.4 million under-treated acres	
8-digit HUC group*	**Sub-region code**	**Subregion name**	Average annual load (1,000 pounds)	Average annual load (1,000 pounds)	Percent reduction	Average annual load (1,000 pounds)	Percent reduction
I	0205	Susquehanna River	87,691	58,756	33	36,811	58
II	0206	Upper Chesapeake**	31,214	28,703	8	15,302	51
III	0207	Potomac River	18,417	15,996	13	8,183	56
IV + V	0208	Lower Chesapeake**	10,411	9,203	12	6,646	36
		Total	147,733	112,658	24	66,942	55

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Loads represent both cropped acres and land in long-term conserving cover. Some columns do not add to totals because of rounding.

Note: Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

*See figure 81.

**Excludes watersheds that drain into the Atlantic Ocean (8-digit HUCs 02060010 and 02080110).

Table 58. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual **nitrogen source loads *delivered to watershed outlets*** (8-digit HUCs) from cultivated cropland for the 4 subregions in the Chesapeake Bay watershed

			Baseline conservation condition	Treatment of 0.8 million critical under-treated acres		Treatment of all 3.4 million under-treated acres	
8-digit HUC group*	**Sub-region code**	**Subregion name**	Average annual load (1,000 pounds)	Average annual load (1,000 pounds)	Percent reduction	Average annual load (1,000 pounds)	Percent reduction
I	0205	Susquehanna River	58,939	40,430	31	26,842	54
II	0206	Upper Chesapeake**	22,592	20,810	8	11,279	50
III	0207	Potomac River	12,761	11,204	12	6,050	53
IV + V	0208	Lower Chesapeake**	7,319	6,621	10	4,954	32
		Total	101,611	79,065	22	49,124	52

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. The differences between loadings in this table and table 54 are due to the application of delivery ratios, which were used to simulate delivery of nitrogen from the edge of the field to the watershed outlet (8-digit HUC). Some columns do not add to totals because of rounding.

Note: Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

*See figure 81.

**Excludes watersheds that drain into the Atlantic Ocean (8-digit HUCs 02060010 and 02080110).

Table 59. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual ***instream nitrogen loads*** from all sources delivered to the Chesapeake Bay

			Baseline conservation condition		Treatment of 0.8 million critical under-treated acres		Treatment of all 3.4 million under-treated acres	
Subregion name	**Sub-region code**	**8-digit HUC group***	Average annual load from all sources (1,000 tons)	Average annual load from background sources** (1,000 tons)	Average annual load (1,000 tons)	Percent reduction	Average annual load (1,000 tons)	Percent reduction
Upper Chesapeake Bay								
Susquehanna River	0205	I	125,260	73,613	108,590	13	96,393	23
Upper Chesapeake	0206	II	46,634	29,343	45,375	3	38,215	18
Potomac River	0207	III	80,365	67,454	78,777	2	73,475	9
Sub-total			252,259	170,410	232,742	8	208,083	18
Lower Chesapeake Bay								
Rappahannock, York, and James Rivers	0208	IV	54,605	48,505	53,870	1	52,495	4
Eastern Shore	0208	V	1,372	858	1,372	0	1,264	8
Sub-total			55,977	49,363	55,242	1	53,759	4
Total			308,236	219,773	287,984	7	261,842	15

*See figure 81.

** “Background sources” represent loads that would be expected if no acres in the watershed were cultivated. These estimates were derived by running an additional scenario that simulated a grass and tree mix cover without any tillage or addition of nutrients or pesticides for all cultivated cropland acres in the watershed. “Background” loads include loads from all other land uses—hayland, pastureland, forestland, and urban land—as well as point sources.

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Some columns do not add to totals because of rounding.

Note: Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

Table 60. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual **phosphorus source loads *delivered to edge of field*** (APEX model output) from cultivated cropland for the 4 subregions in the Chesapeake Bay watershed

			Baseline conservation condition	Treatment of 0.8 million critical under-treated acres		Treatment of all 3.4 million under-treated acres	
8-digit HUC group*	**Sub-region code**	**Subregion name**	Average annual load (1,000 pounds)	Average annual load (1,000 pounds)	Percent reduction	Average annual load (1,000 pounds)	Percent reduction
I	0205	Susquehanna River	9,798	6,162	37	3,630	63
II	0206	Upper Chesapeake**	2,615	2,464	6	1,703	35
III	0207	Potomac River	2,612	2,142	18	1,012	61
IV + V	0208	Lower Chesapeake**	1,157	889	23	415	64
		Total	16,183	11,657	28	6,760	58

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Loads represent both cropped acres and land in long-term conserving cover. Some columns do not add to totals because of rounding.

Note: Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

*See figure 81.

**Excludes watersheds that drain into the Atlantic Ocean (8-digit HUCs 02060010 and 02080110).

Table 61. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual **phosphorus source loads *delivered to watershed outlets*** (8-digit HUCs) from cultivated cropland for the 4 subregions in the Chesapeake Bay watershed

			Baseline conservation condition	Treatment of 0.8 million critical under-treated acres		Treatment of all 3.4 million under-treated acres	
8-digit HUC group*	**Sub-region code**	**Subregion name**	Average annual load (1,000 pounds)	Average annual load (1,000 pounds)	Percent reduction	Average annual load (1,000 pounds)	Percent reduction
I	0205	Susquehanna River	3,702	2,490	33	1,660	55
II	0206	Upper Chesapeake**	1,152	1,099	5	805	30
III	0207	Potomac River	1,077	904	16	476	56
IV + V	0208	Lower Chesapeake**	499	395	21	191	62
		Total	6,430	4,888	24	3,131	51

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. The differences between loadings in this table and table 57 are due to the application of delivery ratios, which were used to simulate delivery of phosphorus from the edge of the field to the watershed outlet (8-digit HUC). Some columns do not add to totals because of rounding.

Note: Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

*See figure 81.

**Excludes watersheds that drain into the Atlantic Ocean (8-digit HUCs 02060010 and 02080110).

Table 62. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual ***instream phosphorus loads*** from all sources delivered to the Chesapeake Bay

			Baseline conservation condition		Treatment of 0.8 million critical under-treated acres		Treatment of all 3.4 million under-treated acres	
Subregion name	**Sub-region code**	**8-digit HUC group***	Average annual load from all sources (1,000 tons)	Average annual load from background sources** (1,000 tons)	Average annual load (1,000 tons)	Percent reduction	Average annual load (1,000 tons)	Percent reduction
Upper Chesapeake Bay								
Susquehanna River	0205	I	3,815	2,522	3,380	11	3,075	19
Upper Chesapeake	0206	II	2,362	1,525	2,311	2	2,086	12
Potomac River	0207	III	4,000	3,086	3,854	4	3,479	13
Sub-total			10,177	7,133	9,544	6	8,639	15
Lower Chesapeake Bay								
Rappahannock, York, and James Rivers	0208	IV	4,544	4,135	4,448	2	4,257	6
Eastern Shore	0208	V	92	75	92	0	92	1
Sub-total			4,636	4,210	4,540	2	4,349	6
Total			14,813	11,342	14,084	5	12,988	12

*See figure 81.

** “Background sources” represent loads that would be expected if no acres in the watershed were cultivated. These estimates were derived by running an additional scenario that simulated a grass and tree mix cover without any tillage or addition of nutrients or pesticides for all cultivated cropland acres in the watershed. “Background” loads include loads from all other land uses—hayland, pastureland, forestland, and urban land—as well as point sources.

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Some columns do not add to totals because of rounding.

Note: Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

Table 63. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual **atrazine source loads *delivered to edge of field*** (APEX model output) from cultivated cropland for the 4 subregions in the Chesapeake Bay watershed

			Baseline conservation condition	Treatment of 0.8 million critical under-treated acres		Treatment of all 3.4 million under-treated acres	
8-digit HUC group*	**Sub-region code**	**Subregion name**	Average annual load (1,000 pounds)	Average annual load (1,000 pounds)	Percent reduction	Average annual load (1,000 pounds)	Percent reduction
I	0205	Susquehanna River	8.55	7.32	14	6.73	21
II	0206	Upper Chesapeake**	4.68	4.64	1	4.46	5
III	0207	Potomac River	3.15	3.04	3	2.86	9
IV + V	0208	Lower Chesapeake**	1.98	1.87	5	1.77	10
		Total	18.35	16.87	8	15.81	14

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Loads represent both cropped acres and land in long-term conserving cover. Some columns do not add to totals because of rounding.

Note: Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

*See figure 81.

**Excludes watersheds that drain into the Atlantic Ocean (8-digit HUCs 02060010 and 02080110).

Table 64. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual **atrazine source loads *delivered to watershed outlets*** (8-digit HUCs) from cultivated cropland for the 4 subregions in the Chesapeake Bay watershed

			Baseline conservation condition	Treatment of 0.8 million critical under-treated acres		Treatment of all 3.4 million under-treated acres	
8-digit HUC group*	**Sub-region code**	**Subregion name**	Average annual load (1,000 pounds)	Average annual load (1,000 pounds)	Percent reduction	Average annual load (1,000 pounds)	Percent reduction
I	0205	Susquehanna River	7.40	6.49	12	6.13	17
II	0206	Upper Chesapeake**	4.26	4.23	1	4.09	4
III	0207	Potomac River	2.80	2.73	3	2.63	6
IV + V	0208	Lower Chesapeake**	1.72	1.65	4	1.56	9
		Total	16.18	15.09	7	14.42	11

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. The differences between loadings in this table and table 60 are due to the application of delivery ratios, which were used to simulate delivery of atrazine from the edge of the field to the watershed outlet (8-digit HUC). Some columns do not add to totals because of rounding.

Note: Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

*See figure 81.

**Excludes watersheds that drain into the Atlantic Ocean (8-digit HUCs 02060010 and 02080110).

Table 65. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual ***instream atrazine loads*** delivered to the Chesapeake Bay

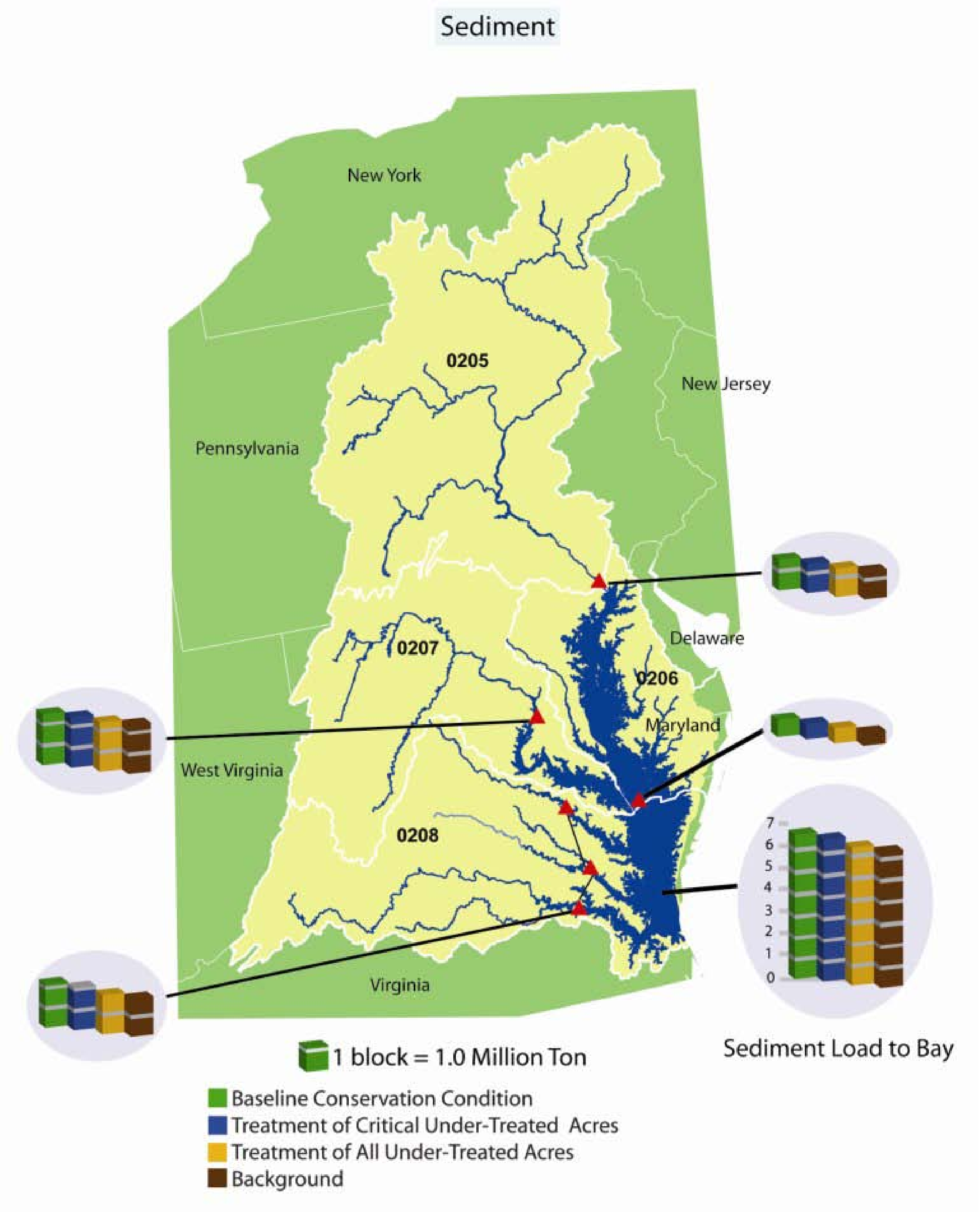
			Baseline conservation condition	Treatment of 0.8 million critical under-treated acres		Treatment of all 3.4 million under-treated acres	
Subregion name	**Sub-region code**	**8-digit HUC group***	Average annual load from all sources (1,000 tons)	Average annual load (1,000 tons)	Percent reduction	Average annual load (1,000 tons)	Percent reduction
Upper Chesapeake Bay							
Susquehanna River	0205	I	4.6	4.1	11	3.9	15
Upper Chesapeake	0206	II	3.0	3.0	1	2.9	4
Potomac River	0207	III	2.4	2.4	2	2.4	3
Sub-total			10.10	9.50	6	9.20	9
Lower Chesapeake Bay							
Rappahannock, York, and James Rivers	0208	IV	1.4	1.4	4	1.3	8
Eastern Shore	0208	V	0.1	0.1	0	0.0	12
Sub-total			1.50	1.44	4	1.37	8
Total			11.59	10.93	6	10.57	9

*See figure 81.

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Some columns do not add to totals because of rounding.

Note: Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

Figure 91. Estimates of average annual instream sediment loads* for the baseline conservation condition compared to two scenarios simulating additional water erosion control and nutrient management practices for subregions in the Chesapeake Bay watershed

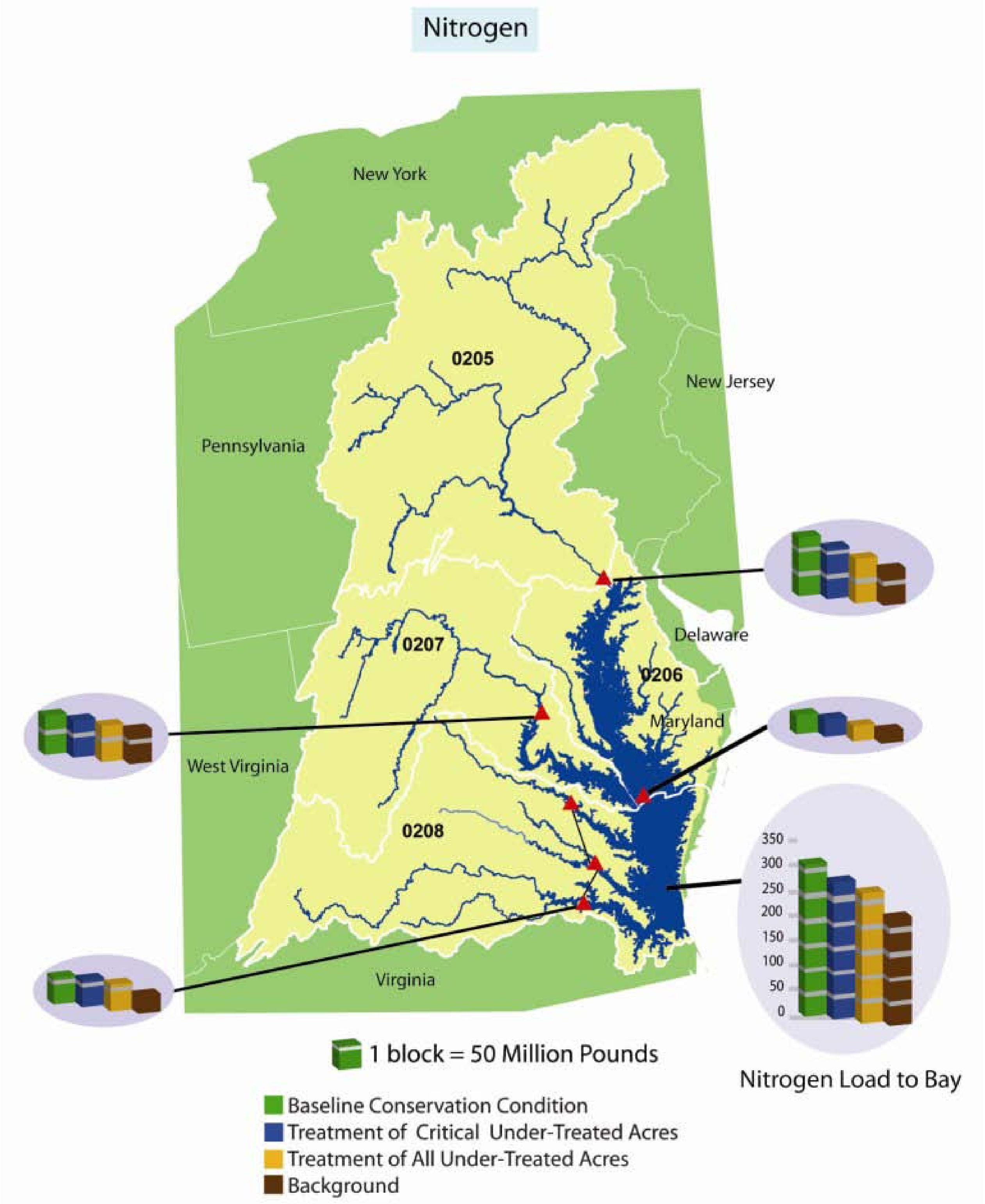


* Instream sediment loads delivered to the Chesapeake Bay (all sources) are shown for each of the four subregions, corresponding to estimates presented in table 56. The total sediment load delivered to the Chesapeake Bay from all areas is shown in the bar chart in the lower right hand corner, labeled “Sediment load to Bay.”

Note: “Background sources” represent loads that would be expected if no acres in the watershed were cultivated. These estimates were derived by running an additional scenario that simulated a grass and tree mix cover without any tillage or addition of nutrients or pesticides for all cultivated cropland acres in the watershed. “Background” loads include loads from all other land uses—hayland, pastureland, forestland, and urban land—as well as point sources.

Note: Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

Figure 92. Estimates of average annual instream nitrogen loads* for the baseline conservation condition compared to two scenarios simulating additional water erosion control and nutrient management practices for subregions in the Chesapeake Bay watershed

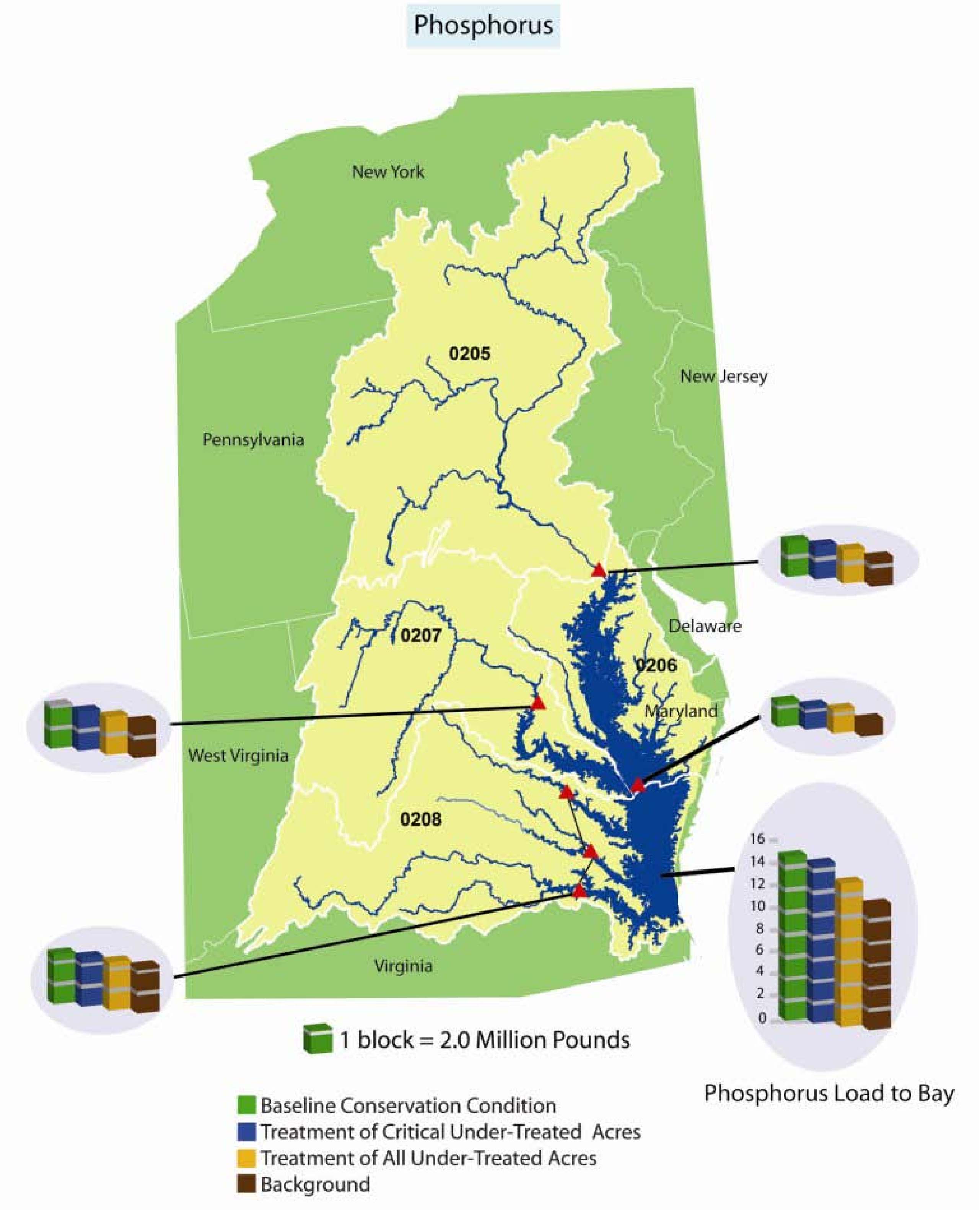


* Instream nitrogen loads delivered to the Chesapeake Bay (all sources) are shown for each of the four subregions, corresponding to estimates presented in table 59. The total nitrogen load delivered to the Chesapeake Bay from all areas is shown in the bar chart in the lower right hand corner, labeled "Nitrogen load to Bay."

Note: "Background sources" represent loads that would be expected if no acres in the watershed were cultivated. These estimates were derived by running an additional scenario that simulated a grass and tree mix cover without any tillage or addition of nutrients or pesticides for all cultivated cropland acres in the watershed. "Background" loads include loads from all other land uses—hayland, pastureland, forestland, and urban land—as well as point sources.

Note: Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

Figure 93. Estimates of average annual instream phosphorus loads* for the baseline conservation condition compared to two scenarios simulating additional water erosion control and nutrient management practices for subregions in the Chesapeake Bay watershed

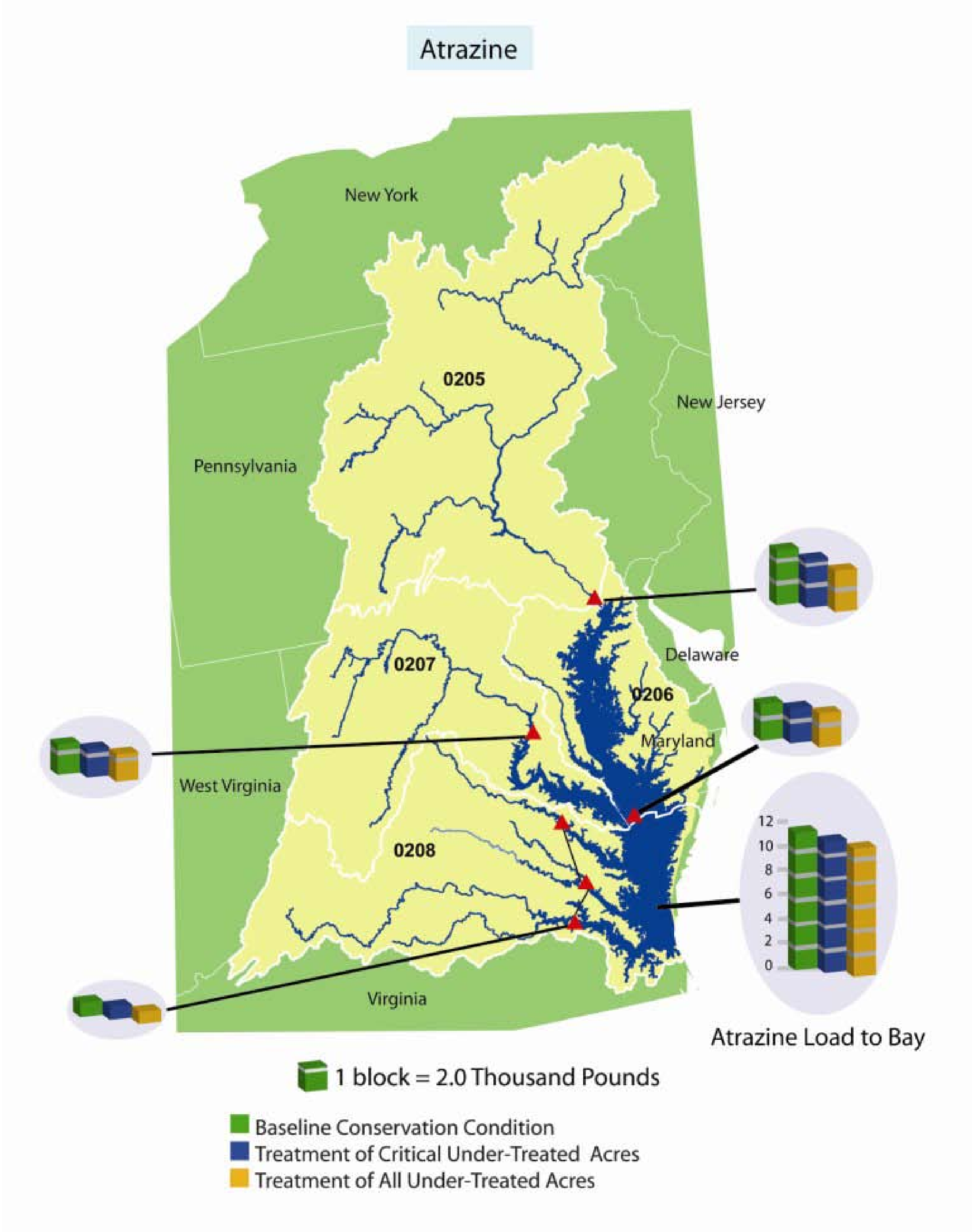


* Instream phosphorus loads delivered to the Chesapeake Bay (all sources) are shown for each of the four subregions, corresponding to estimates presented in table 62. The total phosphorus load delivered to the Chesapeake Bay from all areas is shown in the bar chart in the lower right hand corner, labeled “Phosphorus load to Bay.”

Note: “Background sources” represent loads that would be expected if no acres in the watershed were cultivated. These estimates were derived by running an additional scenario that simulated a grass and tree mix cover without any tillage or addition of nutrients or pesticides for all cultivated cropland acres in the watershed. “Background” loads include loads from all other land uses—hayland, pastureland, forestland, and urban land—as well as point sources.

Note: Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

Figure 94. Estimates of average annual instream atrazine loads* for the baseline conservation condition compared to two scenarios simulating additional water erosion control and nutrient management practices for subregions in the Chesapeake Bay watershed



* Instream atrazine loads delivered to the Chesapeake Bay (all sources) are shown for each of the four subregions, corresponding to estimates presented in table 65. The total atrazine load delivered to the Chesapeake Bay from all areas is shown in the bar chart in the lower right hand corner, labeled "Atrazine load to Bay."

Note: Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

Summary of Conservation Practice Effects on Water Quality in the Chesapeake Bay Watershed

Reductions in field-level losses due to conservation practices, including land in long-term conserving cover, translate into improvements in water quality in streams and rivers in the region. Transport of sediment, nutrients, and pesticides from farm fields to streams and rivers involves a variety of processes and time-lags, and not all of the potential pollutants leaving fields contribute to instream loads.

Cultivated cropland represents only about 10 percent of the land base in the Chesapeake Bay watershed. At the 2003–06 level of conservation practice use, cultivated cropland delivered a disproportionate amount of sediment and nutrients to rivers and streams and ultimately to the Bay. Of the total loads delivered to rivers and streams from all sources, cultivated cropland is the source for 22 percent of the sediment, 28 percent of the phosphorus, and 31 percent of the nitrogen.

Figures 95, 96, and 97 summarize the extent to which conservation practices on cultivated cropland acres have reduced, and can further reduce, sediment, nitrogen, and phosphorus loads in the Chesapeake Bay watershed, on the basis on model simulations.

In each figure, the top map shows delivery from cultivated cropland to rivers and streams and the bottom map shows delivery from all sources to the Bay itself. The effects of practices in use during 2003–06 are seen by contrasting loads for the baseline conservation condition to loads for the no-practice scenario. The effects of additional conservation treatment on loads are seen by contrasting the loads for the baseline condition to either—

1. loads for treatment of acres with a high level of treatment need (0.8 million critical under-treated acres), or
2. loads for treatment of all under-treated acres (3.4 million acres with either a high or moderate level of treatment need).

Background levels, representing loads that would be expected if no acres in the watershed were cultivated, are also shown in the bar charts. These estimates simulate a grass and tree mix cover without any tillage or addition of nutrients or pesticides for all cultivated cropland acres in the watershed. Background loads also include loads from all other land uses—hayland, pastureland, forestland, and urban land—as well as point sources.

Sediment loss

In figure 95, the top map shows that the use of conservation practices has reduced ***sediment loads delivered from cropland to rivers and streams*** in the watershed by 57 percent from conditions that would be expected without conservation practices. It also shows that the application of additional conservation practices could reduce baseline sediment loads delivered to rivers and streams by 39 percent by treating acres with a high level of treatment need and by 84 percent by treating all under-treated acres.

The bottom map shows that the use of conservation practices on cropland has reduced ***sediment loads delivered to Chesapeake Bay from all sources*** by 10 percent from conditions that would be expected without conservation practices. It also shows that the application of additional conservation practices could reduce baseline sediment loads delivered to the Bay by 2 percent by treating acres with a high level of treatment need and by 6 percent by treating all under-treated acres.

Total nitrogen loss

In figure 96, the top map shows that the use of conservation practices has reduced ***total nitrogent loads delivered from cropland to rivers and streams*** in the watershed by 36 percent from conditions that would be expected without conservation practices. It also shows that the application of additional conservation practices could reduce baseline total nitrogen loads delivered to rivers and streams by 22 percent by treating acres with a high level of treatment need and by 52 percent by treating all under-treated acres.

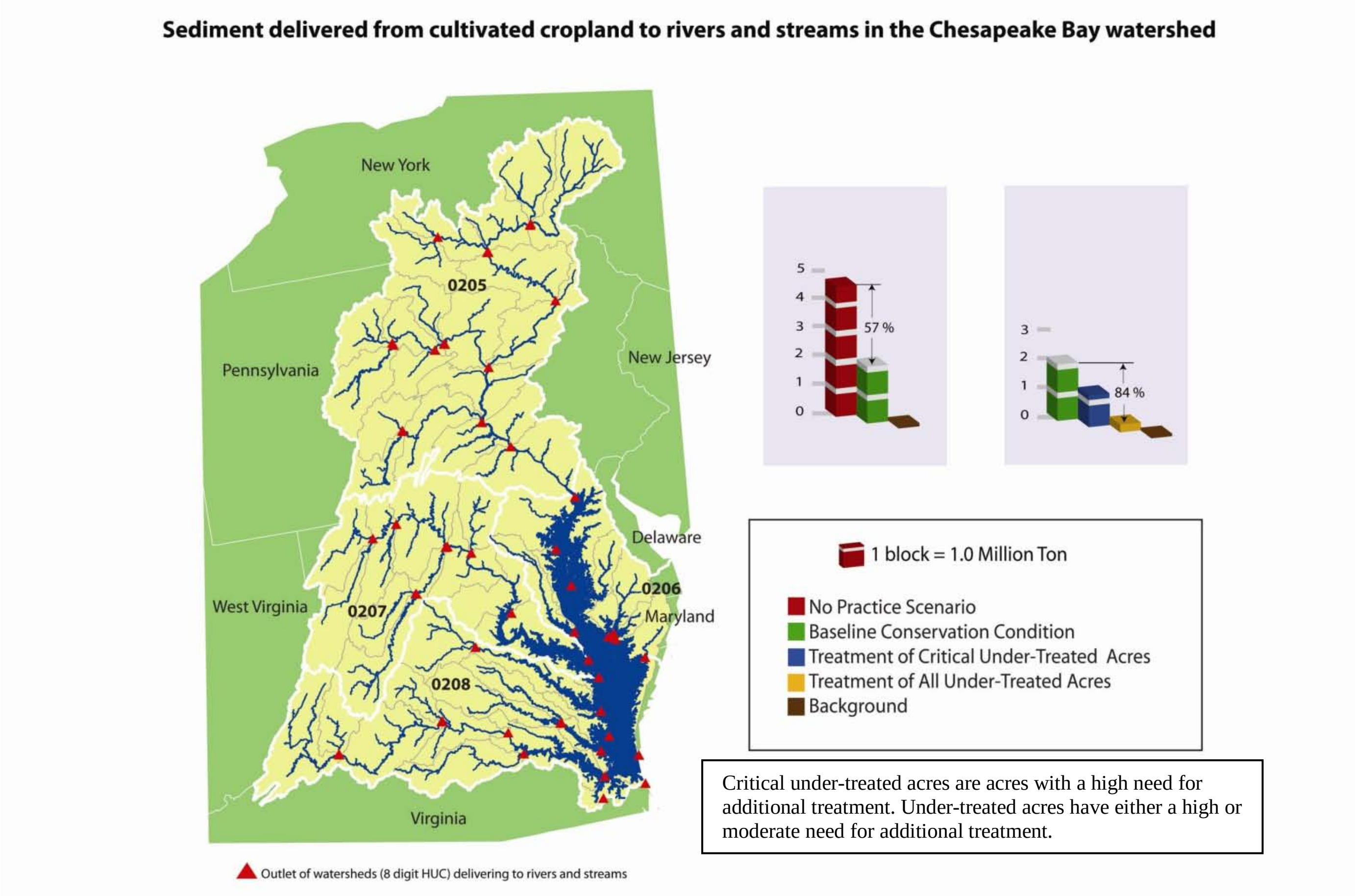
The bottom map shows that the use of conservation practices on cropland has reduced ***total nitrogen loads delivered to Chesapeake Bay from all sources*** by 14 percent from conditions that would be expected without conservation practices. It also shows that the application of additional conservation practices could reduce baseline total nitrogen loads delivered to the Bay by 7 percent by treating acres with a high level of treatment need and by 15 percent by treating all under-treated acres.

Total phosphorus loss

In figure 97, the top map shows that the use of conservation practices has reduced ***total phosphorus loads delivered from cropland to rivers and streams*** in the watershed by 39 percent from conditions that would be expected without conservation practices. It also shows that the application of additional conservation practices could reduce baseline total phosphorus loads delivered to rivers and streams by 24 percent by treating acres with a high level of treatment need and by 51 percent by treating all under-treated acres.

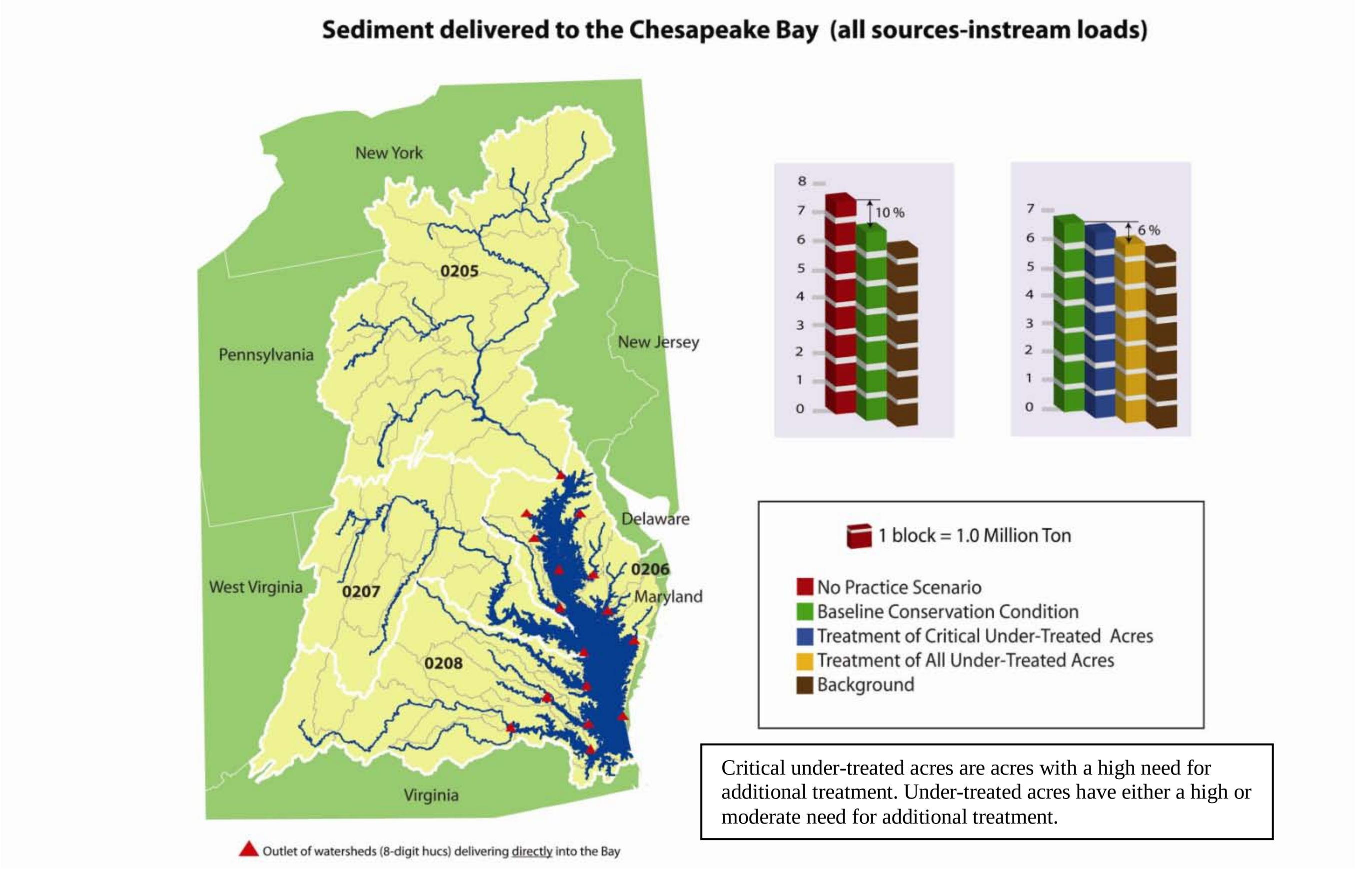
The bottom map shows that the use of conservation practices on cropland has reduced ***total phosphorus loads delivered to Chesapeake Bay from all sources*** by 14 percent from conditions that would be expected without conservation practices. It also shows that the application of additional conservation practices could reduce baseline total phosphorus loads delivered to the Bay by 5 percent by treating acres with a high level of treatment need and by 12 percent by treating all under-treated acres.

Figure 95. Summary of the effects of conservation practices on sediment loads in the Chesapeake Bay watershed



Sediment delivered from cultivated cropland to rivers and streams in the Chesapeake Bay watershed

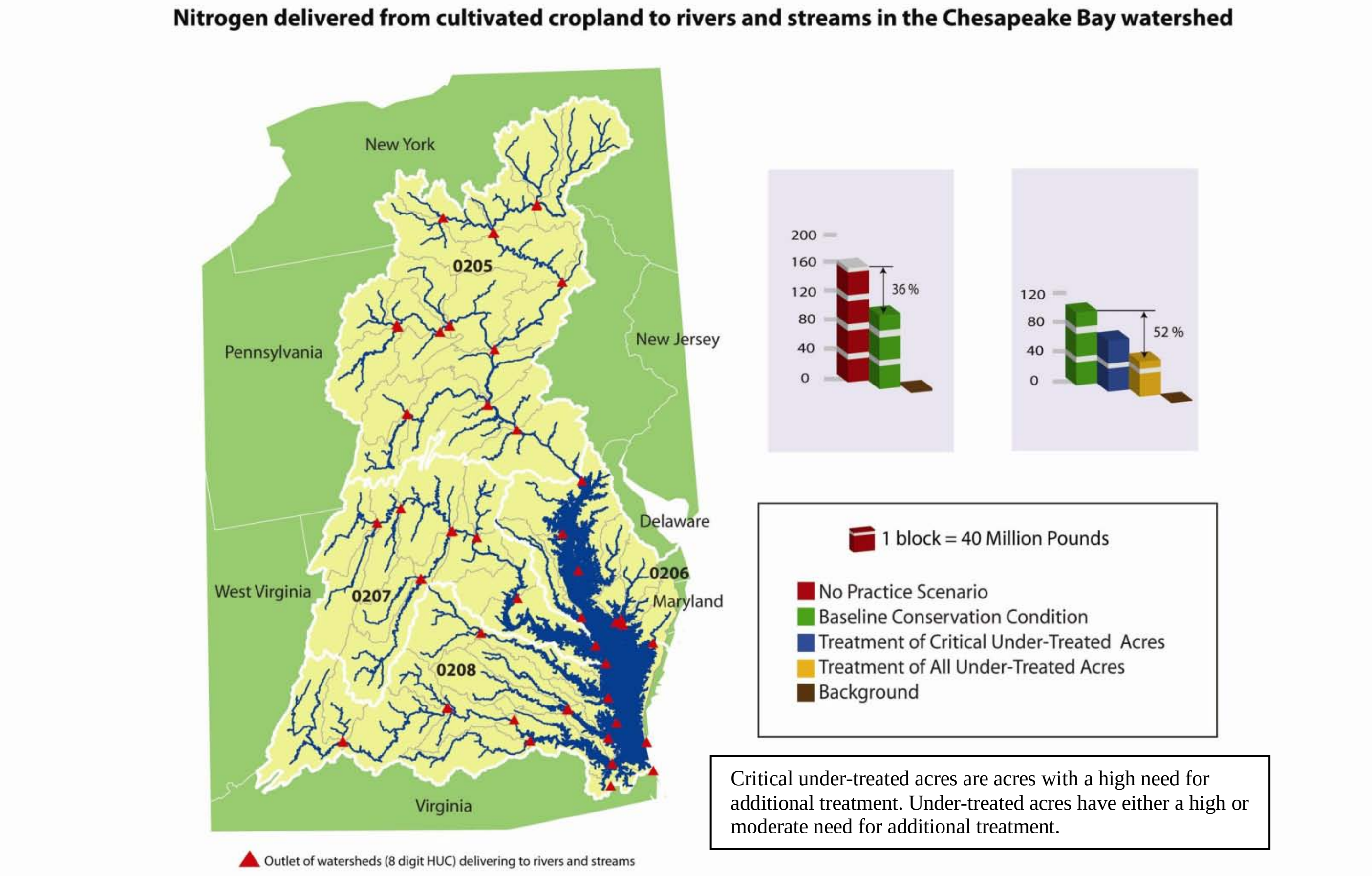
Critical under-treated acres are acres with a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.



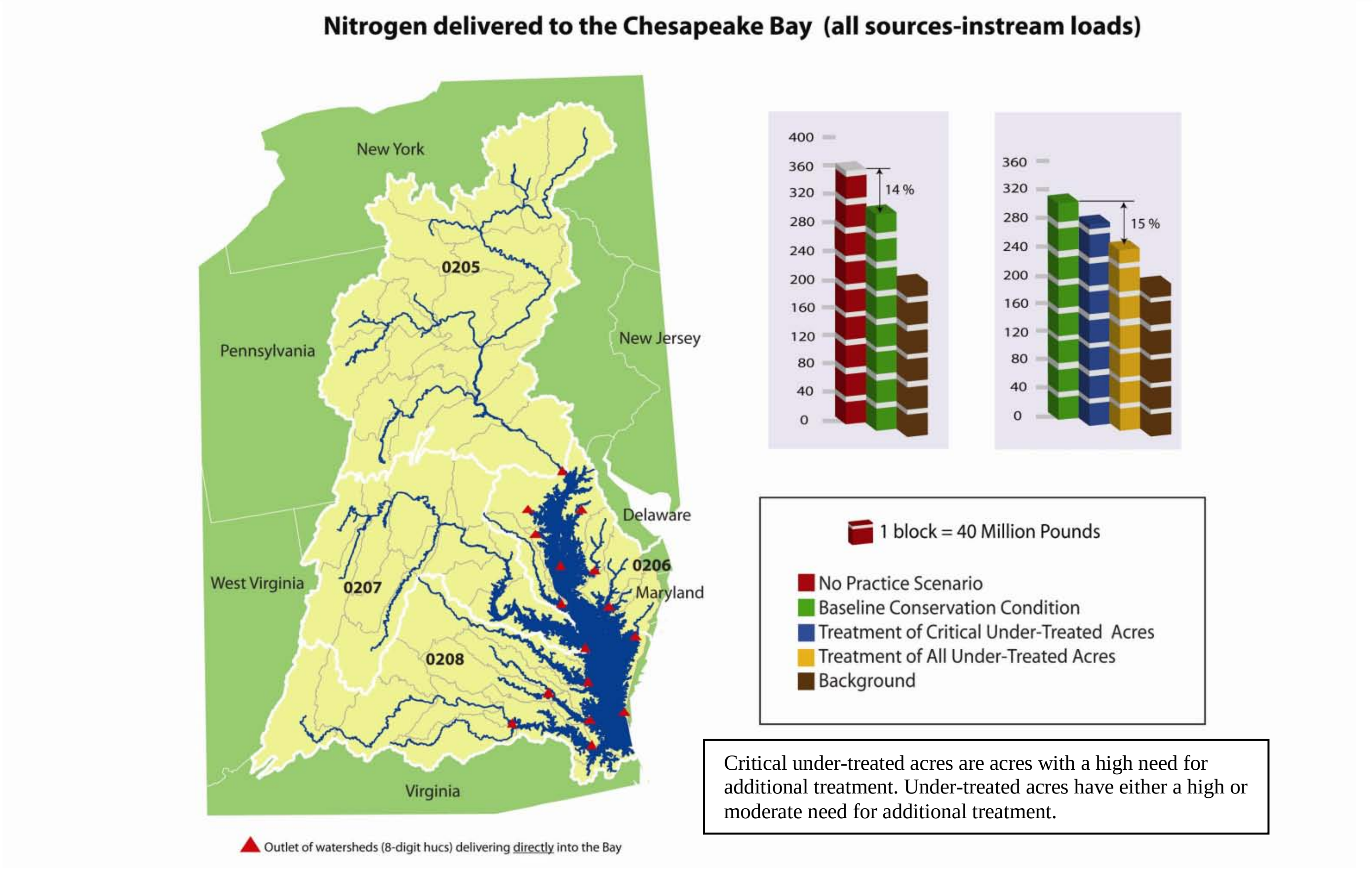
Sediment delivered to the Chesapeake Bay (all sources-instream loads)

Critical under-treated acres are acres with a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

Figure 96. Summary of the effects of conservation practices on total nitrogen loads in the Chesapeake Bay watershed

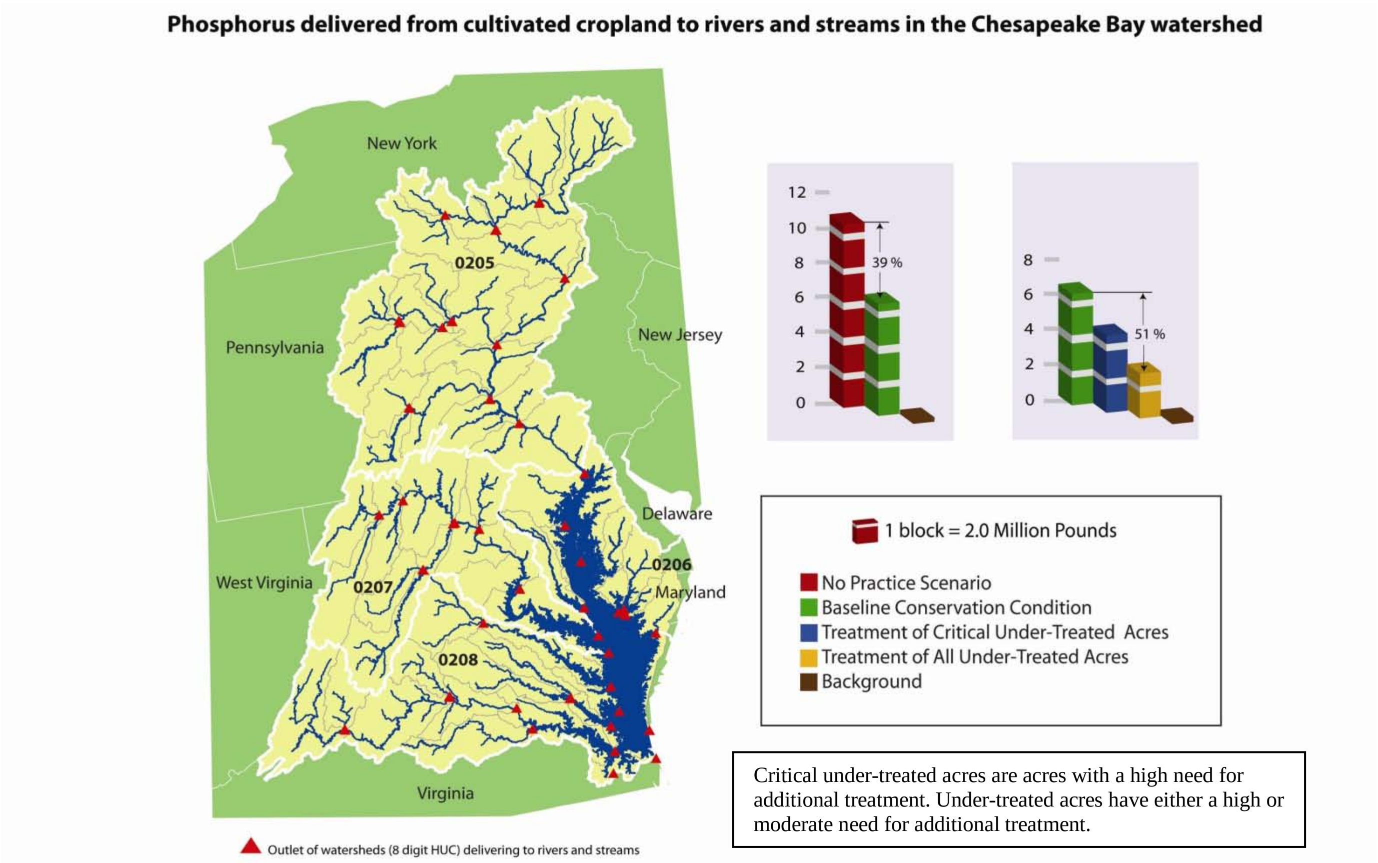

Nitrogen delivered from cultivated cropland to rivers and streams in the Chesapeake Bay watershed

Critical under-treated acres are acres with a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

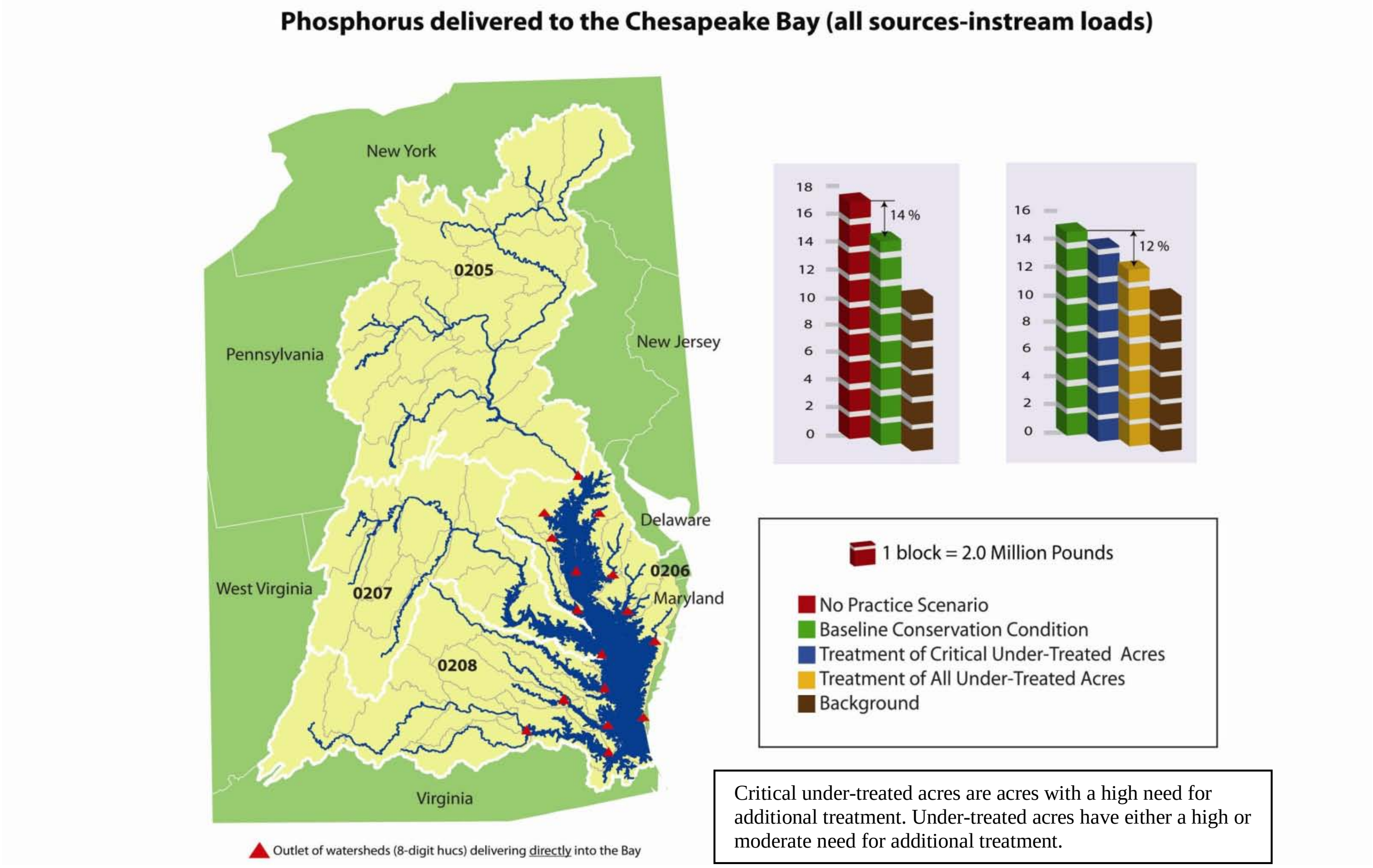

Nitrogen delivered to the Chesapeake Bay (all sources-instream loads)

Critical under-treated acres are acres with a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

Figure 97. Summary of the effects of conservation practices on total phosphorus loads in the Chesapeake Bay watershed


Phosphorus delivered from cultivated cropland to rivers and streams in the Chesapeake Bay watershed

Critical under-treated acres are acres with a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.


Phosphorus delivered to the Chesapeake Bay (all sources-instream loads)

Critical under-treated acres are acres with a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

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Appendix A: Estimates of Margins of Error for Selected Acres Estimates

The CEAP cultivated cropland sample is a subset of NRI sample points from the 2003 NRI (USDA/NRCS 2007). The 2001, 2002, and 2003 Annual NRI surveys were used to draw the sample. (Information about the CEAP sample design is in "NRI-CEAP Cropland Survey Design and Statistical Documentation," available at http://www.nrcs.usda.gov/technical/nri/ceap/Cropland.html.) The sample for cropped acres consists of 771 sample points in the Chesapeake Bay region. Acres reported using the CEAP sample are "estimated" acres because of the uncertainty associated with statistical sampling.

Statistics derived from the CEAP database are based upon data collected at sample sites located across all parts of the region. This means that estimates of acreage are statistical estimates and contain some amount of statistical uncertainty. Since the NRI employs recognized statistical methodology, it is possible to quantify this statistical uncertainty.

Margins of error are provided in table A1 for selected acres estimates found elsewhere in the report. The margin of error is a commonly used measure of statistical uncertainty and can be used to construct a 95-percent confidence interval for an estimate. The lower bound of the confidence interval is obtained by subtracting the margin of error from the estimate; adding the margin of error to the estimate forms the upper bound. Measures of uncertainty (e.g., margins of error, standard errors, confidence intervals, coefficients of variation) should be taken into consideration when using CEAP acreage estimates. The margin of error is calculated by multiplying the standard error by the factor 1.96; a coefficient of variation is the relative standard for an estimate, usually in terms of percentages, and is calculated by taking 100 times the standard error and then dividing by the estimate.

The precision of CEAP estimates depends upon the number of samples within the region of interest, the distribution of the resource characteristics across the region, the sampling procedure, and the estimation procedure. Characteristics that are common and spread fairly uniformly over an area can be estimated more precisely than characteristics that are rare or unevenly distributed.

Table A1. Margins of error for acres estimates based on the CEAP sample

	Estimated acres	Margin of error
Cropped Acres		
Susquehanna River (subregion 0205)	1,734,800	186,358
Upper Chesapeake Bay (subregion 0206)	1,187,900	100,029
Potomac River (subregion 0207)	684,000	102,780
Lower Chesapeake Bay (subregion 0208)	673,200	96,868
Total for Chesapeake Bay region	4,279,900	285,254
Highly erodible land (HEL)		
Susquehanna River (subregion 0205)	1,099,996	129,653
Upper Chesapeake Bay (subregion 0206)	236,129	70,853
Potomac River (subregion 0207)	388,458	86,377
Lower Chesapeake Bay (subregion 0208)	153,532	65,151
Chesapeake Bay region	1,878,115	197,003
Irrigated acres		
Susquehanna River (subregion 0205)	19,734	29,332
Upper Chesapeake Bay (subregion 0206)	144,246	52,336
Potomac River (subregion 0207)	4,779	10,011
Lower Chesapeake Bay (subregion 0208)	40,207	35,788
Chesapeake Bay region	208,966	67,197
Acres receiving manure		
Susquehanna River (subregion 0205)	913,625	247,935
Upper Chesapeake Bay (subregion 0206)	401,765	85,069
Potomac River (subregion 0207)	293,993	96,762
Lower Chesapeake Bay (subregion 0208)	7,805	8,812
Chesapeake Bay region	1,617,188	307,753

Table A1—continued.

	Estimated acres	Margin of error
Cropping Systems (table 5)		
Corn-soybean only	1,174,736	175,174
Corn-soybean with close grown crops	830,308	134,871
Corn only	690,403	140,309
Soybean only	161,087	76,210
Soybean-wheat only	124,649	73,605
Corn and close grown crops	295,685	90,258
Vegetable or tobacco with or without other crops	139,064	89,212
Hay-crop mix	688,255	154,400
Remaining mix of crops	175,713	75,284
Use of structural practices (table 6)		
Overland flow control practices	1,439,296	251,808
Concentrated flow control practices	736,132	175,173
Edge-of-field buffering and filtering practices	446,780	112,200
One or more water erosion control practices	1,984,945	284,974
Wind erosion control practices	279,491	87,013
Use of cover crops	177,833	89,132
Use of residue and tillage management (table 7)	2,063,175	
Average annual tillage intensity for crop rotation meets criteria for no-till	1,704,087	232,726
Average annual tillage intensity for crop rotation meets criteria for mulch till	217,776	81,729
Reduced tillage on some crops in rotation but average annual tillage intensity greater than criteria for mulch till	294,862	115,854
Continuous conventional tillage in every year of crop rotation	2,063,175	251,622
Use of structural practices and/or residue and tillage management (table 8)		
No-till or mulch till with carbon gain, no structural practices	887,102	139,950
No-till or mulch till with carbon loss, no structural practices	1,131,758	161,413
Some crops with reduced tillage, no structural practices	102,999	56,947
Structural practices and no-till or mulch till with carbon gain	833,385	195,619
Structural practices and no-till or mulch till with carbon loss	915,018	220,180
Structural practices and some crops with reduced tillage	114,777	68,957
Structural practices only	121,766	70,460
No water erosion control treatment	173,096	90,688
Conservation treatment levels for structural practices (fig. 7)		
High level of treatment	220,173	80,248
Moderately high level of treatment	580,243	124,035
Moderate level of treatment	1,184,529	258,234
Low level of treatment	2,294,955	231,431
Conservation treatment levels for residue and tillage management (fig. 8)		
High level of treatment	1,496,831	207,528
Moderately high level of treatment	237,248	87,882
Moderate level of treatment	2,321,320	273,439
Low level of treatment	224,501	96,499
Conservation treatment levels for nitrogen management (fig. 9)		
High level of treatment	459,334	105,938
Moderately high level of treatment	1,167,435	205,512
Moderate level of treatment	1,698,549	254,086
Low level of treatment	954,583	212,129

Table A1—continued.

	Estimated acres	Margin of error
Conservation treatment levels for phosphorus management (fig. 10)		
High level of treatment	765,841	154,429
Moderately high level of treatment	854,467	175,852
Moderate level of treatment	596,832	147,210
Low level of treatment	2,062,760	274,489
Conservation treatment levels for IPM (fig. 11)		
High level of treatment	402,008	147,771
Moderate level of treatment	1,632,206	198,019
Low level of treatment	2,245,686	249,316
Conservation treatment levels for water erosion control practices (fig. 52)		
High level of treatment	672,167	94,822
Moderately high level of treatment	680,848	192,428
Moderate level of treatment	2,145,424	253,327
Low level of treatment	781,462	126,956
Conservation treatment levels for nitrogen runoff control (fig. 53)		
High level of treatment	30,182	32,450
Moderately high level of treatment	985,946	137,331
Moderate level of treatment	2,508,040	240,887
Low level of treatment	755,732	163,926
Conservation treatment levels for phosphorus runoff control (fig. 54)		
High level of treatment	89,838	35,753
Moderately high level of treatment	942,710	151,782
Moderate level of treatment	1,948,614	243,610
Low level of treatment	1,298,738	207,490
Soil runoff potential (fig. 55)		
High	979,325	170,751
Moderately high	812,140	151,116
Moderate	496,021	184,386
Low	1,992,414	238,387
Soil leaching potential (fig. 57)		
High	717,434	109,658
Moderately high	1,249,166	206,858
Moderate	2,038,260	207,679
Low	275,040	85,229
Level of conservation treatment need by resource concern		
Sediment loss (table 23)		
High (critical under-treated)	202,678	97,623
Moderate (non-critical under-treated)	837,465	202,408
Low (adequately treated)	3,239,757	282,145
Nitrogen loss with surface runoff (sediment attached and soluble) (table 24)		
High (critical under-treated)	158,399	70,567
Moderate (non-critical under-treated)	853,062	213,029
Low (adequately treated)	3,268,439	260,176
Nitrogen loss in subsurface flows (table 25)		
High (critical under-treated)	425,019	165,626
Moderate (non-critical under-treated)	2,228,113	252,230
Low (adequately treated)	1,626,768	236,866
Phosphorus lost to surface water (table 26)		
High (critical under-treated)	386,555	110,788
Moderate (non-critical under-treated)	1,789,656	216,815
Low (adequately treated)	2,103,689	170,245

Table A1—continued.

	Estimated acres	**Margin of error**
Level of conservation treatment need for one or more resource concerns		
Chesapeake Bay region (table 27)		
High (critical under-treated)	809,997	173,113
Moderate (non-critical under-treated)	2,597,927	176,929
Low (adequately treated)	871,976	159,339
Susquehanna River (subregion 0205) (table 29)		
High (critical under-treated)	558,625	137,577
Moderate (non-critical under-treated)	905,625	145,439
Low (adequately treated)	270,549	142,794
Upper Chesapeake Bay (subregion 0206) (table 29)		
High (critical under-treated)	92,499	40,360
Moderate (non-critical under-treated)	770,379	85,598
Low (adequately treated)	325,022	78,352
Potomac River (subregion 0207) (table 29)		
High (critical under-treated)	120,517	44,224
Moderate (non-critical under-treated)	469,746	105,285
Low (adequately treated)	93,737	40,513
Lower Chesapeake Bay (subregion 0208) (table 29)		
High (critical under-treated)	38,356	32,205
Moderate (non-critical under-treated)	452,177	99,913
Low (adequately treated)	182,667	70,619

Appendix B: Model Simulation Results for the Baseline Conservation Condition for the Four Subregions in the Chesapeake Bay Region

Model simulation results presented in Chapter 4 for the baseline conservation condition are presented in tables B-1 and B-2 for the four subregions in the Chesapeake Bay region.

The column headings refer to the subregion code. The names of the subregions are shown below:

Subregion code	Subregion name
0205	Susquehanna River
0206	Upper Chesapeake
0207	Potomac River
0208	Lower Chesapeake

Table B-1. Average annual estimates of water flow, erosion, and soil organic carbon for the baseline conservation condition for cropped acres, by subregion, in the Chesapeake Bay region

Model simulated outcome	Chesapeake Bay region	0205	0206	0207	0208
Cropped acres (million acres)	4,279,900	1,734,800	1,187,900	684,000	673,200
Percent of acres in region	100%	41%	28%	16%	16%
Percent of acres highly erodible	44%	63%	20%	57%	23%
Percent of acres irrigated	5%	1%	12%	1%	6%
Percent of acres receiving manure	38%	53%	34%	43%	1%
Water sources (average annual inches)					
Non-irrigated acres					
Precipitation	42	41	44	41	44
Irrigated acres					
Precipitation	43	38	44	40	41
Irrigation water applied	12	10	14	10	11
Water loss pathways (average annual inches)					
Evapotranspiration	27.7	26.7	28.2	28.0	29.4
Surface water runoff	5.1	5.2	5.9	3.9	4.5
Subsurface water flow	10.7	9.6	12.3	8.9	12.6
Erosion and sediment loss (average annual tons/acre)					
Wind erosion	0.03	0.02	0.04	0.01	0.05
Sheet and rill erosion	0.99	1.54	0.50	0.99	0.44
Sediment loss at edge of field due to water erosion	1.18	2.05	0.43	1.02	0.43
Soil organic carbon (average annual pounds/acre)					
Loss of soil organic carbon with wind and water erosion	152	191	126	139	110
Change in soil organic carbon, including loss of carbon with wind and water erosion	-27	-68	-14	27	3

Table B-2. Average annual estimates of nitrogen loss, phosphorus loss, and pesticide loss for the baseline conservation condition for cropped acres, by subregion, in the Chesapeake Bay region

Model simulated outcome	Chesapeake Bay region	0205	0206	0207	0208
Nitrogen (average annual pounds/acre)					
Nitrogen sources					
Atmospheric deposition	8.7	9.7	7.5	8.5	8.6
Bio-fixation by legumes	26.4	18.4	34.6	22.6	36.3
Nitrogen applied as commercial fertilizer and manure	95.3	102.1	87.5	105.5	81.2
All nitrogen sources	130.4	130.2	129.6	136.6	126.0
Nitrogen in crop yield removed at harvest	84.1	73.7	92.2	85.0	95.6
Nitrogen loss pathways					
Nitrogen loss by volatilization	6.9	5.8	7.4	8.2	7.6
Nitrogen loss through denitrification processes	1.6	2.0	1.0	1.9	1.5
Nitrogen lost with windborne sediment	0.2	0.1	0.3	0.1	0.2
Nitrogen loss with surface runoff , including waterborne sediment	8.8	12.9	5.4	8.3	4.9
Nitrogen loss in subsurface flow pathways	32.7	43.2	25.7	32.5	18.2
Total nitrogen loss for all pathways except harvest	50.2	63.9	39.8	51.0	32.4
Change in soil nitrogen	-5.2	-9.3	-3.4	-0.6	-2.8
Phosphorus (average annual pounds/acre)					
Phosphorus applied as commercial fertilizer and manure	25.2	29.5	19.1	31.4	18.8
Phosphorus in crop yield removed at harvest	13.3	11.9	14.2	13.6	14.9
Phosphorus loss pathways					
Phosphorus lost with windborne sediment	0.03	0.02	0.05	0.03	0.04
Phosphorus lost to surface runoff, including waterborne sediment and soluble phosphorus in surface water runoff and lateral flow into drainage ditches	3.67	5.25	2.07	4.39	1.67
Soluble phosphorus loss to groundwater	0.07	0.08	0.06	0.07	0.06
Total phosphorus loss for all pathways except harvest	3.77	5.35	2.18	4.49	1.77
Change in soil phosphorus	8.1	12.1	2.6	13.3	2.2
Pesticides					
Average annual amount of pesticides applied (grams of active ingredient/hectare)	2,000	1,733	2,061	2,178	2,397
Pesticide loss					
Average annual mass loss of pesticides for all pathways (grams of active ingredient/hectare)	15	15	14	17	12
Edge-of-field pesticide risk indicator					
Average annual surface water pesticide risk indicator for aquatic ecosystem	1.8	1.9	1.5	2.1	1.6
Average annual surface water pesticide risk indicator for humans	0.4	0.4	0.4	0.6	0.4
Average annual groundwater pesticide risk indicator for humans	0.4	0.3	0.4	0.5	0.2

Appendix C: Simulation of Full Adoption of Cover Crops in the Chesapeake Bay Region

Use of cover crops in the Chesapeake Bay region is increasing, particularly where state incentive programs have been implemented. Cover crops in the Bay Area are planted in the fall and then tilled or killed with herbicides (or by some other means) prior to the spring planting. When used properly, cover crops protect the soil from erosion during the winter months, take up nutrients remaining in the soil, and release plant available nutrients slowly over the subsequent cropping period, thereby reducing nutrient leaching and runoff during the non-growing season.

The 2003–06 NRI-CEAP survey found that only about 4 percent of the cropped acres in the Chesapeake Bay region had cover crops during the time period when the survey was conducted. The baseline conservation condition for 2003–06 included only 31 sample points where a cover crop was used in the rotation, representing only about 200,000 acres, and these samples had on average a cover crop about every other year. Consequently, the benefits of cover crop adoption in the region at the current rate could not be estimated from this study.

To demonstrate the potential for cover crops to reduce sediment and nutrient loss from fields in this region, a special "what if" scenario was conducted to simulate the use of cover crops on all cropped acres. Cover crops were inserted into the crop rotations of the baseline according to the following rules:

1. For every sample, in every crop year, the crop rotation was examined and if no crop was growing during the traditional winter period, a cover crop was "planted" the day after harvest, or the day after the last major fall tillage operation. The crop was allowed to grow until the time of the first spring tillage operation, or 1 week before the planting operation, in the case of a no-till spring planting.
2. Rye was used as the cover crop.
3. There was no other change to the baseline other than the addition of a broadcast seeder to plant the cover crop in the fall.

After the model and data setup were completed, it was found that 14 samples had neither an original nor a newly added cover crop, representing about 64,000 acres. These samples had, in each year of the rotation, either a winter small grain crop that was harvested in the spring or a hay crop present, so that there was no opportunity to add a cover crop.

The field-level results of the cover crop simulation are contrasted to the original baseline scenario in table C1 for the Chesapeake Bay region as a whole and separately for each of the 4 subregions in tables C2-C5.

Precipitation and nutrient inputs were the same for both scenarios. For irrigated acres, irrigation water use in the cover crop scenario increased slightly—about 6 percent on average—because of depetition of soil moisture by the cover crop and a somewhat higher demand for water by the crops that followed the cover crop.[25] Biofixation of nitrogen by legumes decreased by an average of about 1 pound per acre due to the presence of cover crops (table C1). Crop yields were very slightly affected by the presence of the cover crop; the uptake and removal of nitrogen and phosphorus at harvest—indicators of crop yield—decreased by an average of only about 1 percent for nitrogen and 2 percent for phosphorus (table C1).

Water loss pathways would only be slightly altered by the addition of cover crops (table C1). Evapotranspiration would increase only about 6 percent overall, and surface water runoff would decrease slightly (3 percent). However, subsurface flows would decrease about 1.4 inches per year (13 percent), on average, due primarily to water uptake by the cover crop.

Erosion and Sediment Loss

Erosion and sediment loss would be dramatically reduced for the region as a whole by the addition of cover crops on all acres (table C1). Wind erosion would be reduced 76 percent, on average, compared to the 2003–06 baseline condition. Sediment loss would be reduced by an average of 0.7 tons per acre per year, a 59 percent reduction, bringing the average annual sediment loss for the region to less than 0.5 tons per acre per year. The potential for reducing sediment loss using cover crops is greatest in the Potomac River and the Lower Chesapeake subregions, where reductions in sediment loss would be expected to exceed 70 percent (tables C4-C5) compared to the 2003–06 baseline condition.

However, figures C1 and C2 show that the effects of cover crops on reducing sediment loss is modest for the majority of cropped acres—generally those with the lowest losses in the 2003–06 baseline condition. The median sediment loss reduction would be only about 0.2 tons per acre per year. About 60 percent of the acres would have a reduction in sediment loss of 0.35 tons per acre or less (fig. C2). In contrast, 18 percent of the acres would have average annual reductions of 1 ton per acre or more. Nonetheless, figure 1 shows that full adoption of cover crops would bring average annual sediment loss to below 2 tons per acre for 93 percent of the acres in the region, compared to 83 percent for the 2003–06 baseline condition.

Soil Organic Carbon

Soil organic carbon levels would increase on more cropped acres and decrease more slowly on other cropped acres if cover crops were used and the biomass retained on the field. The annual change in soil organic carbon would average about 97 pounds per acre higher (table C1). A portion of this gain would be due to a reduction in the loss of soil organic carbon from the field due to wind and water erosion (26 percent reduction, on average). Figure C3 shows that if cover crops were added to all cropped acres that 27 percent of cropped acres would move from losing soil organic carbon to gaining

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[25] In the model, irrigation water is applied automatically when the plant stress level exceeds a threshold; for some irrigated acres in some years, the presence of the cover crop reduced soil moisture enough to trigger additional application of irrigation water during the crop growing season.

soil organic carbon, bringing acres that are gaining soil organic carbon to 70 percent of cropped acres in the region. The potential for gains in soil organic carbon due to cover crop use are greatest in the Potomac River and Susquehanna River subregions (tables C2 and C4).

Nitrogen loss

Model simulations show that use of cover crops has a significant impact on nitrogen loss from fields. All of the nitrogen loss pathways are affected by the addition of cover crops. For the region as a whole—

- Nitrogen loss by volatilization would increase by an average of 3.8 pounds per acre per year (from 6.9 to 10.7 pounds per acre), representing a 55-percent increase compared to the 2003–06 baseline condition;
- Nitrogen loss through denitrification would increase by an average of 0.7 pound per acre per year (from 1.6 to 2.3 pounds per acre), representing a 44-percent increase compared to the 2003–06 baseline condition;
- Nitrogen lost with windborne sediment would decrease a very small amount;
- Nitrogen loss with surface runoff, including waterborne sediment, would decrease an average of 4.0 pounds per acre per year (from 8.8 to 4.8 pounds per acre), representing a 46-percent decrease; and
- Nitrogen loss in subsurface flow pathways would decrease an average of 10 pounds per acre per year (from 33 to 23 pounds per acre), representing a 31-percent decrease.

Total nitrogen loss through all loss pathways would be reduced from an average of 50.2 pounds per acre per year to 40.5 pounds per acre per year, representing a 19-percent decrease overall. As shown in figures C4 and C5, the effects of cover crops on total nitrogen loss vary; one-third of the acres would be expected to have loss reductions less than 5 pounds per acre, about 19 percent of the acres would be expected to have loss reductions greater than 15 pounds per acre (ranging to as high as 30 or more), and about half of the acres would be expected to have loss reductions between 5 and 15 pounds per acre.

For water quality concerns, the most important loss pathway affected by cover crops is nitrogen loss in subsurface flow pathways (figs. C6 and C7), followed by nitrogen lost with surface runoff (figs. C8 and C9). While these reductions in nitrogen loss due to cover crop use are significant, they are not uniform across all the acres. For nitrogen loss in subsurface flows, 30 percent of the acres would be expected to have loss reductions less than 5 pounds per acre, while about 10 percent of the acres would be expected to have loss reductions greater than 20 pounds per acre. For nitrogen lost with surface runoff, half of the acres would be expected to have loss reductions less than 2 pounds per acre, while about 10 percent of the acres would be expected to have loss reductions greater than 10 pounds per acre.

The other significant loss pathway affected by cover crops is nitrogen loss by volatilization (fig. C10). The increase in nitrogen volatilization is due to decaying vegetation and the re-routing of nitrogen among the loss pathways. For example, nitrogen that had been lost with runoff and leaching without cover crops present is now being physically held in place or chemically retained in plant biomass and thus more available to degradation processes, resulting in more nitrogen lost in gaseous forms. While losses of nitrogen through volatilization are no longer available to water loss pathways, a portion of these nitrogen compounds may return to waterways through atmospheric deposition, depending on the kind of nitrogen compounds volatilizing. The median volatilization loss for the region is about 8.6 pounds per acre with cover crops used on all acres, compared to 5.5 pounds per acre for the 2003–06 baseline condition (fig. C10).

Cover crops would be equally effective in reducing total nitrogen loss in all four subregions in the region (tables C2-C5). For nitrogen loss in subsurface flows, the largest per-acre reduction—12.6 pounds per acre—would occur in the Potomac River subregion (table C4), while the greatest percent reduction—54 percent—would occur in the Lower Chesapeake (table C5).

Phosphorus loss

Cover crops would also be effective in reducing total phosphorus loss, although the effects are more pronounced on some acres than others. Total phosphorus loss through all loss pathways would be reduced from an average of 3.8 pounds per acre per year to 2.6 pounds per acre per year, representing a 32-percent decrease overall. Only a small amount of phosphorus is lost with windborne sediment or to groundwater. The bulk is lost to surface water, which includes waterborne sediment and soluble phosphorus in surface water runoff as well as lateral flow into drainage ditches, tile drains, and natural seeps. The reduction in total phosphorus loss due to cover crop use is shown in figures C11 and C12. About half of the acres would be expected to have loss reductions less than 0.5 pound per acre, while about 15 percent of the acres would be expected to have loss reductions greater than 2 pounds per acre. While the potential for cover crops to reduce phosphorus loss is about the same in the four regions in terms of the percent reductions, per-acre reductions would be highest—averaging over 1.5 pounds per acre—in the Potomac River and Susquehanna River subregions (tables C2 and C4).

Figure C1. Estimates of average annual sediment loss for cropped acres, comparing the baseline scenario to a "what if" scenario with cover crops added to all cropped acres, Chesapeake Bay region

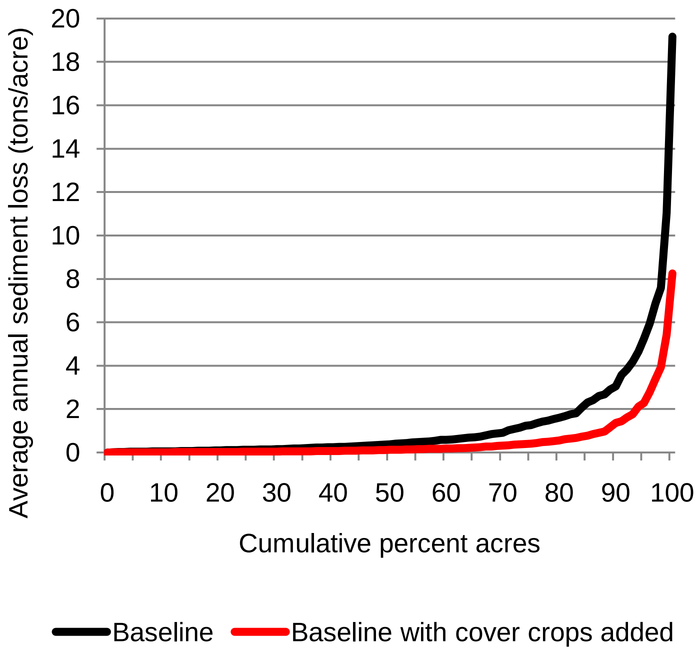

Figure C2. Estimates of the average annual potential reduction in sediment loss if cover crops were used on all cropped acres in the Chesapeake Bay region

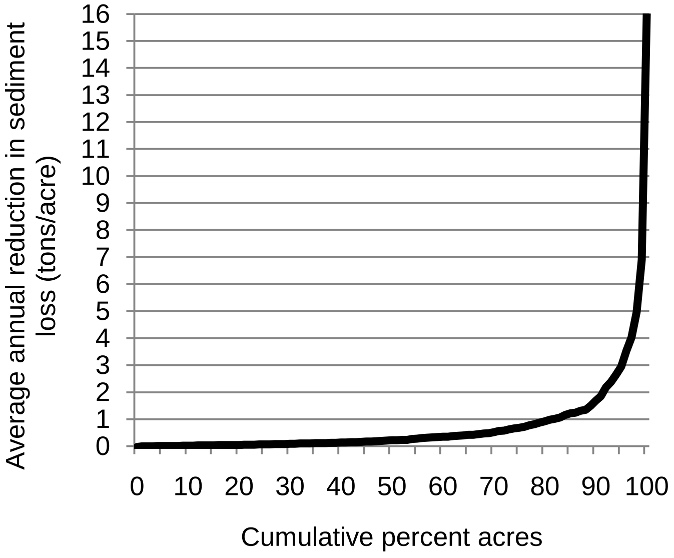

Figure C3. Estimates of average annual change in soil organic carbon for cropped acres, comparing the baseline scenario to a "what if" scenario with cover crops added to all cropped acres, Chesapeake Bay region

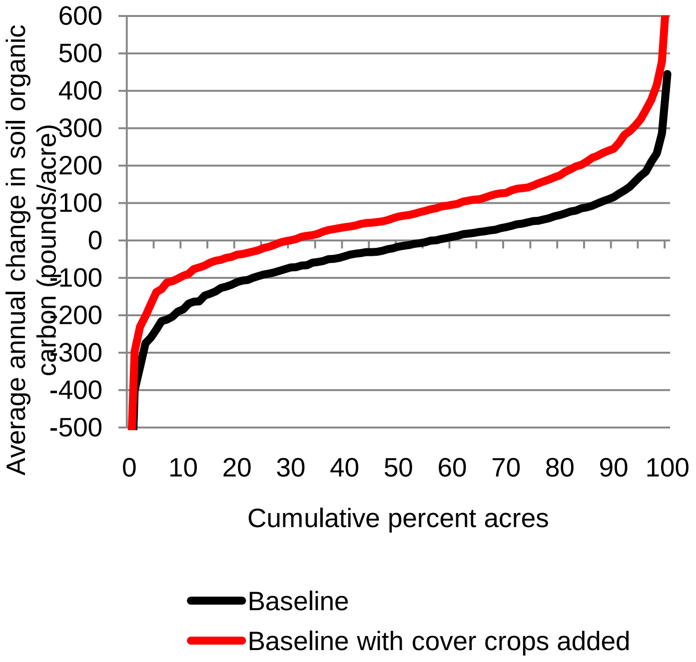

Figure C4. Estimates of average annual total nitrogen loss for cropped acres, comparing the baseline scenario to a "what if" scenario with cover crops added to all cropped acres, Chesapeake Bay region

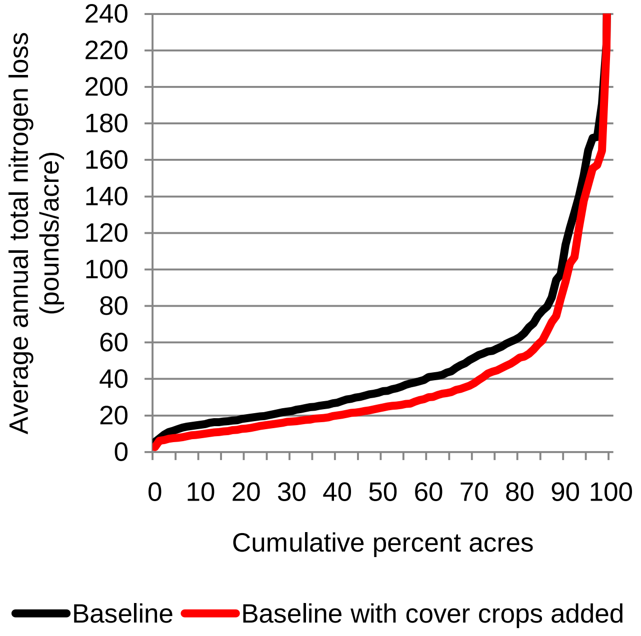

Figure C5. Estimates of the average annual potential reduction in total nitrogen loss if cover crops were used on all cropped acres in the Chesapeake Bay region

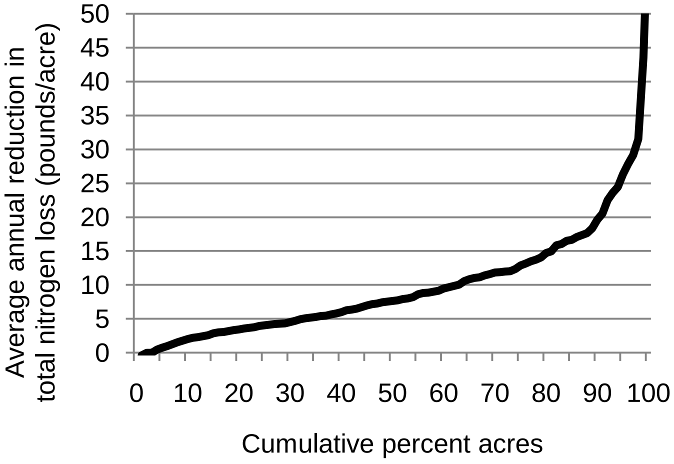

Figure C6. Estimates of average annual nitrogen loss in subsurface flows for cropped acres, comparing the baseline scenario to a "what if" scenario with cover crops added to all cropped acres, Chesapeake Bay region

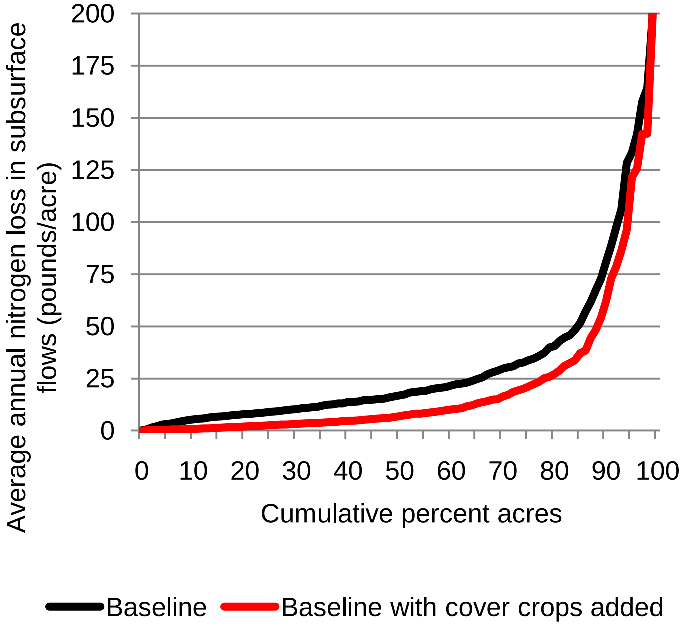

Figure C7. Estimates of the average annual potential reduction in nitrogen loss in subsurface flows if cover crops were used on all cropped acres in the Chesapeake Bay region

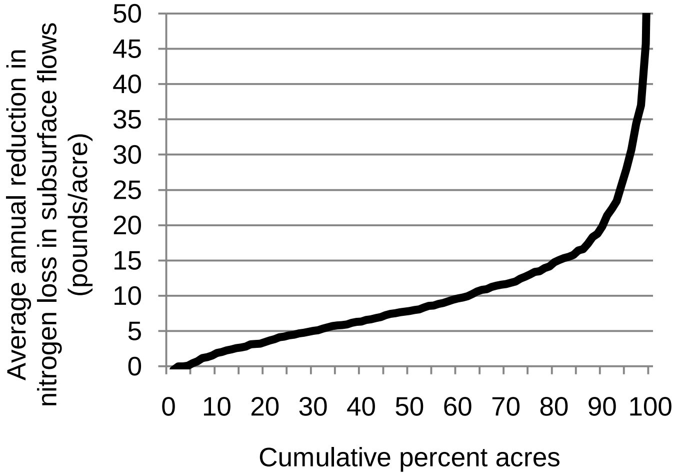

Figure C8. Estimates of average annual nitrogen lost with surface runoff (including waterborne sediment) for cropped acres, comparing the baseline scenario to a "what if" scenario with cover crops added to all cropped acres, Chesapeake Bay region

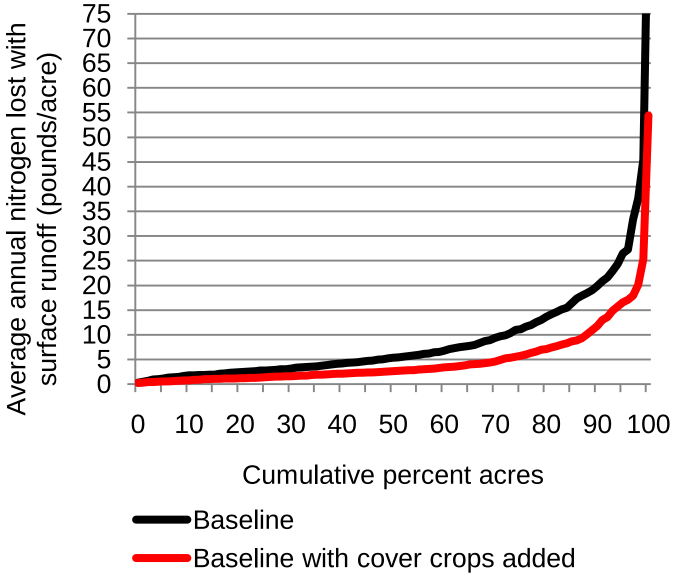

Figure C9. Estimates of the average annual potential reduction in nitrogen lost with surface runoff (including waterborne sediment) if cover crops were used on all cropped acres in the Chesapeake Bay region

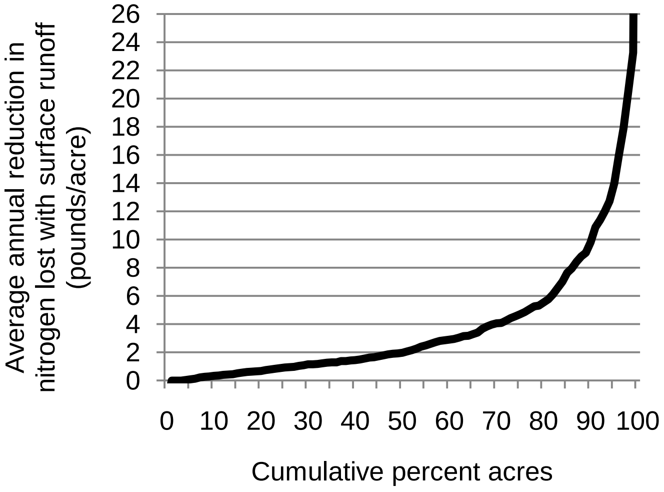

Figure C10. Estimates of average annual nitrogen loss by volatilization for cropped acres, comparing the baseline scenario to a "what if" scenario with cover crops added to all cropped acres, Chesapeake Bay region

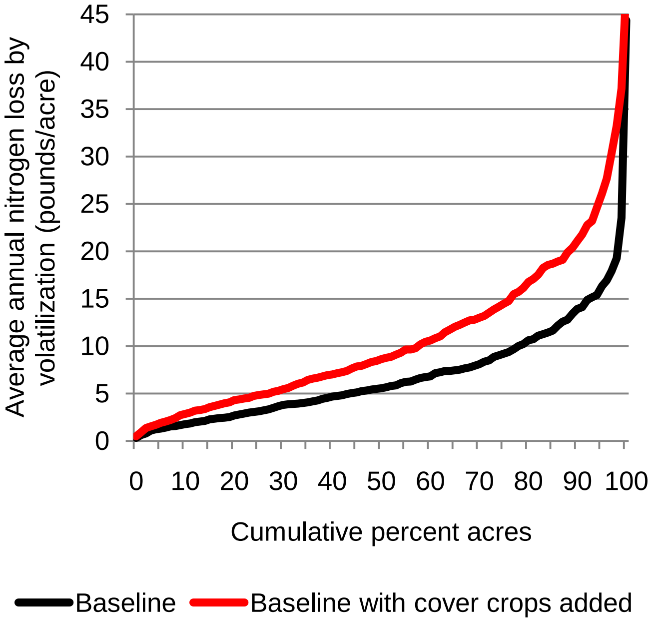

Figure C11. Estimates of average annual total phosphorus loss for cropped acres, comparing the baseline scenario to a "what if" scenario with cover crops added to all cropped acres, Chesapeake Bay region

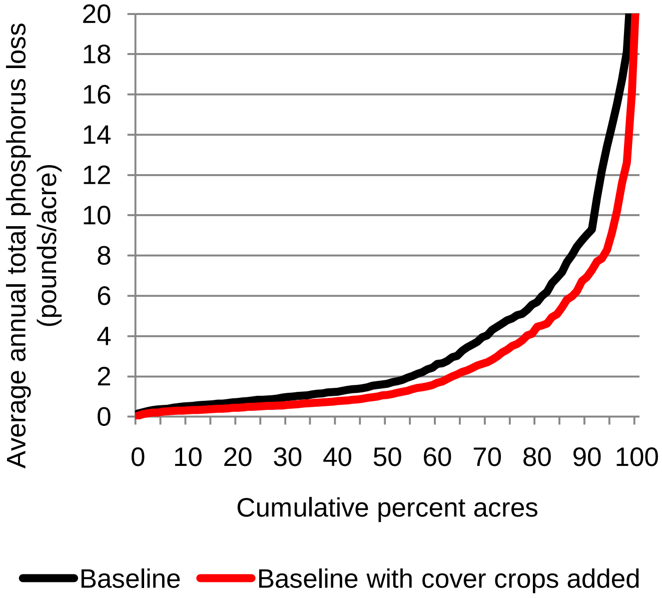

Figure C12. Estimates of the average annual potential reduction in total phosphorus loss if cover crops were used on all cropped acres in the Chesapeake Bay region

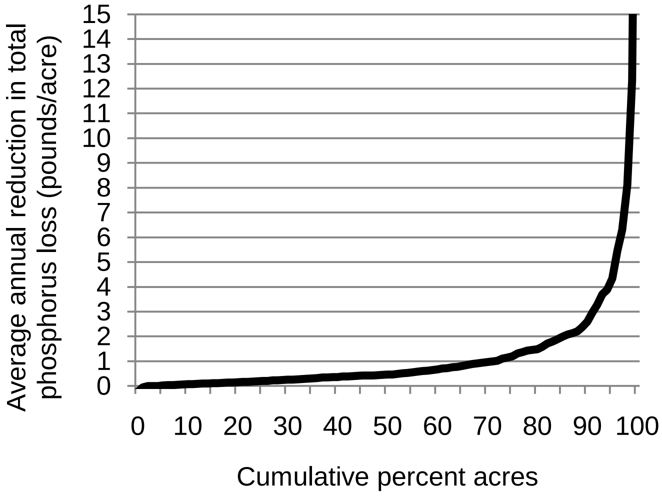

Table C1. Average annual estimates of water flow, erosion, soil organic carbon, nitrogen loss, and phosphorus loss for the baseline conservation condition compared to a “what if” scenario with cover crops on all acres, Chesapeake Bay region (4.280 million acres)

Model simulated outcome	**Baseline condition**	**Baseline condition with cover crops added***	**Change due to cover crops****	**Percent change due to cover crops**
Water sources (average annual inches)				
Non-irrigated acres				
Precipitation	42.2	42.2	0.0	0%
Irrigated acres				
Precipitation	42.8	42.8	0.0	0%
Irrigation water applied	12.3	13.0	0.8	6%
Water loss pathways (average annual inches)				
Evapotranspiration	27.7	29.4	1.7	6%
Surface water runoff	5.1	4.9	-0.2	-3%
Subsurface water flow	10.7	9.3	-1.4	-13%
Erosion and sediment loss (average annual tons/acre)				
Wind erosion	0.027	0.006	-0.021	-76%
Sheet and rill erosion	0.99	0.56	-0.43	-44%
Sediment loss at edge of field due to water erosion	1.18	0.48	-0.70	-59%
Soil organic carbon (average annual pounds/acre)				
Loss of soil organic carbon with wind and water erosion	152	113	-39	-26%
Change in soil organic carbon, including loss of carbon with wind and water erosion	-27	71	97	--
Nitrogen (average annual pounds/acre)				
Nitrogen sources				
Atmospheric deposition	8.7	8.7	0.0	0%
Bio-fixation by legumes	26.4	25.3	-1.1	-4%
Nitrogen applied as commercial fertilizer and manure	95.3	95.3	0.0	0%
All nitrogen sources	130.4	129.3	-1.1	-1%
Nitrogen in crop yield removed at harvest	84.1	83.5	-0.6	-1%
Nitrogen loss pathways				
Nitrogen loss by volatilization	6.9	10.7	3.8	55%
Nitrogen loss through denitrification processes	1.6	2.3	0.7	44%
Nitrogen lost with windborne sediment	0.2	0.0	-0.1	-77%
Nitrogen loss with surface runoff , including waterborne sediment	8.8	4.8	-4.0	-46%
Nitrogen loss in subsurface flow pathways	32.7	22.7	-10.1	-31%
Total nitrogen loss for all pathways	50.2	40.5	-9.7	-19%
Change in soil nitrogen	-5.2	4.1	9.3	--
Phosphorus (average annual pounds/acre)				
Phosphorus applied as commercial fertilizer and manure	25.2	25.2	0.0	0%
Phosphorus in crop yield removed at harvest	13.28	13.00	-0.28	-2%
Phosphorus loss pathways				
Phosphorus lost with windborne sediment	0.03	0.01	-0.03	-79%
Phosphorus lost to surface runoff, including waterborne sediment and soluble phosphorus in surface water runoff and lateral flow into drainage ditches	3.67	2.51	-1.16	-32%
Soluble phosphorus loss to groundwater	0.07	0.05	-0.01	-20%
Total phosphorus loss for all pathways	3.77	2.57	-1.20	-32%
Change in soil phosphorus	8.11	9.63	1.52	--

* If no crop was already growing, or newly planted after the fall (or late summer) harvest, a cover crop was planted the day after harvest, or the day after the last major fall tillage operation if there were any. The crop was allowed to grow until one week before the first spring tillage operation, or 1 week before the planting operation if a no-till planting. The simulated cover crop was rye.

** Baseline with cover crops added minus original baseline.

Note: Reductions and percent reductions were calculated prior to rounding the values for reporting in the table and the associated text.

Table C2. Average annual estimates of water flow, erosion, soil organic carbon, nitrogen loss and phosphorus loss for the baseline conservation condition compared to a “what if” scenario with cover crops on all acres, Susquehanna River (Subregion code 0205, 1.735 million acres)

Model simulated outcome	**Baseline condition**	**Baseline condition with cover crops added***	**Change due to cover crops****	**Percent change due to cover crops**
Water sources (average annual inches)				
Non-irrigated acres				
Precipitation	41.3	41.3	0.0	0%
Irrigated acres				
Precipitation	38.2	38.2	0.0	0%
Irrigation water applied	9.1	9.6	0.4	5%
Water loss pathways (average annual inches)				
Evapotranspiration	26.7	27.6	0.9	3%
Surface water runoff	5.2	5.1	-0.1	-2%
Subsurface water flow	9.6	8.8	-0.7	-8%
Erosion and sediment loss (average annual tons/acre)				
Wind erosion	0.017	0.005	-0.012	-72%
Sheet and rill erosion	1.54	0.96	-0.58	-38%
Sediment loss at edge of field due to water erosion	2.05	0.93	-1.12	-55%
Soil organic carbon (average annual pounds/acre)				
Loss of soil organic carbon with wind and water erosion	191	129	-62	-33%
Change in soil organic carbon, including loss of carbon with wind and water erosion	-68	41	110	--
Nitrogen (average annual pounds/acre)				
Nitrogen sources				
Atmospheric deposition	9.7	9.7	0.0	0%
Bio-fixation by legumes	18.4	17.8	-0.7	-4%
Nitrogen applied as commercial fertilizer and manure	102.1	102.1	0.0	0%
All nitrogen sources	130.2	129.6	-0.6	0%
Nitrogen in crop yield removed at harvest	73.7	74.1	0.4	1%
Nitrogen loss pathways				
Nitrogen loss by volatilization	5.8	8.0	2.3	39%
Nitrogen loss through denitrification processes	2.0	2.7	0.7	37%
Nitrogen lost with windborne sediment	0.1	0.0	-0.1	-73%
Nitrogen loss with surface runoff , including waterborne sediment	12.9	7.4	-5.5	-43%
Nitrogen loss in subsurface flow pathways	43.2	34.6	-8.6	-20%
Total nitrogen loss for all pathways	63.9	52.7	-11.2	-18%
Change in soil nitrogen	-9.3	1.1	10.4	--
Phosphorus (average annual pounds/acre)				
Phosphorus applied as commercial fertilizer and manure	29.5	29.5	0.0	0%
Phosphorus in crop yield removed at harvest	11.88	11.71	-0.17	-1%
Phosphorus loss pathways				
Phosphorus lost with windborne sediment	0.02	0.01	-0.02	-78%
Phosphorus lost to surface runoff, including waterborne sediment and soluble phosphorus in surface water runoff and lateral flow into drainage ditches	5.25	3.60	-1.66	-32%
Soluble phosphorus loss to groundwater	0.08	0.07	-0.01	-12%
Total phosphorus loss for all pathways	5.35	3.67	-1.68	-31%
Change in soil phosphorus	12.14	14.04	1.90	--

* If no crop was already growing, or newly planted after the fall (or late summer) harvest, a cover crop was planted the day after harvest, or the day after the last major fall tillage operation if there were any. The crop was allowed to grow until one week before the first spring tillage operation, or 1 week before the planting operation if a no-till planting. The simulated cover crop was rye.

** Baseline with cover crops added minus original baseline.

Note: Reductions and percent reductions were calculated prior to rounding the values for reporting in the table and the associated text.

Table C3. Average annual estimates of water flow, erosion, soil organic carbon, nitrogen loss and phosphorus loss for the baseline conservation condition compared to a “what if” scenario with cover crops on all acres, Upper Chesapeake (Subregion code 0206, 1.188 million acres)

Model simulated outcome	Baseline condition	Baseline condition with cover crops added*	Change due to cover crops**	Percent change due to cover crops
Water sources (average annual inches)				
Non-irrigated acres				
Precipitation	43.8	43.8	0.0	0%
Irrigated acres				
Precipitation	43.9	43.9	0.0	0%
Irrigation water applied	13.5	14.3	0.8	6%
Water loss pathways (average annual inches)				
Evapotranspiration	28.2	30.5	2.3	8%
Surface water runoff	5.9	5.7	-0.2	-4%
Subsurface water flow	12.3	10.3	-2.0	-16%
Erosion and sediment loss (average annual tons/acre)				
Wind erosion	0.036	0.006	-0.029	-82%
Sheet and rill erosion	0.50	0.24	-0.26	-51%
Sediment loss at edge of field due to water erosion	0.43	0.15	-0.29	-66%
Soil organic carbon (average annual pounds/acre)				
Loss of soil organic carbon with wind and water erosion	126	113	-13	-10%
Change in soil organic carbon, including loss of carbon with wind and water erosion	-14	69	83	--
Nitrogen (average annual pounds/acre)				
Nitrogen sources				
Atmospheric deposition	7.5	7.5	0.0	0%
Bio-fixation by legumes	34.6	33.1	-1.5	-4%
Nitrogen applied as commercial fertilizer and manure	87.5	87.4	0.0	0%
All nitrogen sources	129.6	128.0	-1.5	-1%
Nitrogen in crop yield removed at harvest	92.2	90.8	-1.4	-1%
Nitrogen loss pathways				
Nitrogen loss by volatilization	7.4	12.3	4.9	66%
Nitrogen loss through denitrification processes	1.0	1.5	0.6	57%
Nitrogen lost with windborne sediment	0.3	0.0	-0.2	-83%
Nitrogen loss with surface runoff , including waterborne sediment	5.4	2.8	-2.6	-48%
Nitrogen loss in subsurface flow pathways	25.7	14.9	-10.8	-42%
Total nitrogen loss for all pathways	39.8	31.6	-8.2	-21%
Change in soil nitrogen	-3.4	4.8	8.1	--
Phosphorus (average annual pounds/acre)				
Phosphorus applied as commercial fertilizer and manure	19.1	19.1	0.0	0%
Phosphorus in crop yield removed at harvest	14.24	13.88	-0.36	-3%
Phosphorus loss pathways				
Phosphorus lost with windborne sediment	0.05	0.01	-0.04	-82%
Phosphorus lost to surface runoff, including waterborne sediment and soluble phosphorus in surface water runoff and lateral flow into drainage ditches	2.07	1.47	-0.60	-29%
Soluble phosphorus loss to groundwater	0.06	0.04	-0.02	-28%
Total phosphorus loss for all pathways	2.18	1.53	-0.65	-30%
Change in soil phosphorus	2.64	3.67	1.03	--

* If no crop was already growing, or newly planted after the fall (or late summer) harvest, a cover crop was planted the day after harvest, or the day after the last major fall tillage operation if there were any. The crop was allowed to grow until one week before the first spring tillage operation, or 1 week before the planting operation if a no-till planting. The simulated cover crop was rye.

** Baseline with cover crops added minus original baseline.

Note: Reductions and percent reductions were calculated prior to rounding the values for reporting in the table and the associated text.

Table C4. Average annual estimates of water flow, erosion, soil organic carbon, nitrogen loss and phosphorus loss for the baseline conservation condition compared to a “what if” scenario with cover crops on all acres, Potomac River (Subregion code 0207, 0.684 million acres)

Model simulated outcome	Baseline condition	Baseline condition with cover crops added*	Change due to cover crops**	Percent change due to cover crops
Water sources (average annual inches)				
Non-irrigated acres				
Precipitation	40.6	40.6	0.0	0%
Irrigated acres				
Precipitation	39.7	39.7	0.0	0%
Irrigation water applied	9.3	11.2	1.9	20%
Water loss pathways (average annual inches)				
Evapotranspiration	28.0	29.6	1.6	6%
Surface water runoff	3.9	3.7	-0.2	-5%
Subsurface water flow	8.9	7.5	-1.4	-16%
Erosion and sediment loss (average annual tons/acre)				
Wind erosion	0.013	0.002	-0.011	-86%
Sheet and rill erosion	0.99	0.44	-0.55	-56%
Sediment loss at edge of field due to water erosion	1.02	0.27	-0.75	-74%
Soil organic carbon (average annual pounds/acre)				
Loss of soil organic carbon with wind and water erosion	139	94	-46	-33%
Change in soil organic carbon, including loss of carbon with wind and water erosion	27	150	123	--
Nitrogen (average annual pounds/acre)				
Nitrogen sources				
Atmospheric deposition	8.5	8.5	0.0	0%
Bio-fixation by legumes	22.6	21.6	-1.0	-4%
Nitrogen applied as commercial fertilizer and manure	105.5	105.5	0.0	0%
All nitrogen sources	136.6	135.6	-1.0	-1%
Nitrogen in crop yield removed at harvest	85.0	83.5	-1.5	-2%
Nitrogen loss pathways				
Nitrogen loss by volatilization	8.2	13.0	4.8	59%
Nitrogen loss through denitrification processes	1.9	3.1	1.2	60%
Nitrogen lost with windborne sediment	0.1	0.0	-0.1	-79%
Nitrogen loss with surface runoff , including waterborne sediment	8.3	3.7	-4.6	-55%
Nitrogen loss in subsurface flow pathways	32.5	19.9	-12.6	-39%
Total nitrogen loss for all pathways	50.9	39.7	-11.2	-22%
Change in soil nitrogen	-0.6	11.3	11.9	--
Phosphorus (average annual pounds/acre)				
Phosphorus applied as commercial fertilizer and manure	31.4	31.4	0.0	0%
Phosphorus in crop yield removed at harvest	13.61	13.16	-0.45	-3%
Phosphorus loss pathways				
Phosphorus lost with windborne sediment	0.03	0.00	-0.02	-83%
Phosphorus lost to surface runoff, including waterborne sediment and soluble phosphorus in surface water runoff and lateral flow into drainage ditches	4.39	2.88	-1.51	-34%
Soluble phosphorus loss to groundwater	0.07	0.05	-0.01	-23%
Total phosphorus loss for all pathways	4.49	2.93	-1.55	-35%
Change in soil phosphorus	13.25	15.34	2.09	--

* If no crop was already growing, or newly planted after the fall (or late summer) harvest, a cover crop was planted the day after harvest, or the day after the last major fall tillage operation if there were any. The crop was allowed to grow until one week before the first spring tillage operation, or 1 week before the planting operation if a no-till planting. The simulated cover crop was rye.

** Baseline with cover crops added minus original baseline.

Note: Reductions and percent reductions were calculated prior to rounding the values for reporting in the table and the associated text.

Table C5. Average annual estimates of water flow, erosion, soil organic carbon, nitrogen loss and phosphorus loss for the baseline conservation condition compared to a “what if” scenario with cover crops on all acres, Lower Chesapeake (Subregion code 0208, 0.673 million acres)

Model simulated outcome	Baseline condition	Baseline condition with cover crops added*	Change due to cover crops**	Percent change due to cover crops
Water sources (average annual inches)				
Non-irrigated acres				
Precipitation	43.7	43.7	0.0	0%
Irrigated acres				
Precipitation	41.3	41.3	0.0	0%
Irrigation water applied	10.0	10.5	0.5	5%
Water loss pathways (average annual inches)				
Evapotranspiration	29.3	31.9	2.6	9%
Surface water runoff	4.5	4.3	-0.3	-6%
Subsurface water flow	12.6	10.5	-2.2	-17%
Erosion and sediment loss (average annual tons/acre)				
Wind erosion	0.051	0.015	-0.036	-71%
Sheet and rill erosion	0.44	0.20	-0.25	-55%
Sediment loss at edge of field due to water erosion	0.43	0.12	-0.31	-71%
Soil organic carbon (average annual pounds/acre)				
Loss of soil organic carbon with wind and water erosion	110	93	-17	-15%
Change in soil organic carbon, including loss of carbon with wind and water erosion	3	67	64	--
Nitrogen (average annual pounds/acre)				
Nitrogen sources				
Atmospheric deposition	8.6	8.6	0.0	0%
Bio-fixation by legumes	36.3	34.8	-1.5	-4%
Nitrogen applied as commercial fertilizer and manure	81.2	81.2	0.0	0%
All nitrogen sources	126.0	124.5	-1.5	-1%
Nitrogen in crop yield removed at harvest	95.6	95.0	-0.6	-1%
Nitrogen loss pathways				
Nitrogen loss by volatilization	7.6	12.5	4.9	64%
Nitrogen loss through denitrification processes	1.4	1.9	0.4	29%
Nitrogen lost with windborne sediment	0.2	0.1	-0.2	-68%
Nitrogen loss with surface runoff , including waterborne sediment	4.9	2.6	-2.3	-48%
Nitrogen loss in subsurface flow pathways	18.2	8.5	-9.8	-54%
Total nitrogen loss for all pathways	32.4	25.5	-7.0	-21%
Change in soil nitrogen	-2.8	3.4	6.2	--
Phosphorus (average annual pounds/acre)				
Phosphorus applied as commercial fertilizer and manure	18.8	18.8	0.0	0%
Phosphorus in crop yield removed at harvest	14.86	14.61	-0.25	-2%
Phosphorus loss pathways				
Phosphorus lost with windborne sediment	0.04	0.01	-0.03	-72%
Phosphorus lost to surface runoff, including waterborne sediment and soluble phosphorus in surface water runoff and lateral flow into drainage ditches	1.67	1.16	-0.51	-31%
Soluble phosphorus loss to groundwater	0.06	0.04	-0.02	-33%
Total phosphorus loss for all pathways	1.77	1.21	-0.56	-32%
Change in soil phosphorus	2.15	2.97	0.81	--

* If no crop was already growing, or newly planted after the fall (or late summer) harvest, a cover crop was planted the day after harvest, or the day after the last major fall tillage operation if there were any. The crop was allowed to grow until one week before the first spring tillage operation, or 1 week before the planting operation if a no-till planting. The simulated cover crop was rye.

** Baseline with cover crops added minus original baseline.

Note: Reductions and percent reductions were calculated prior to rounding the values for reporting in the table and the associated text.