United States Department of Agriculture
Natural Resources Conservation Service

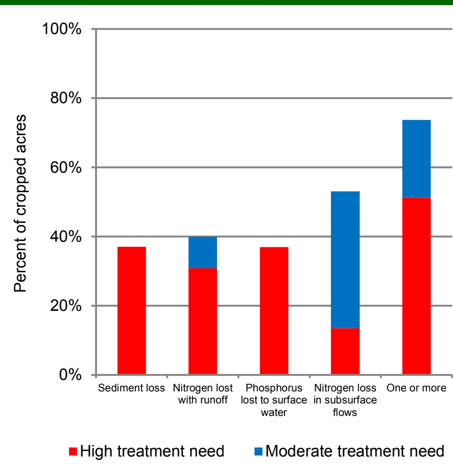
Conservation Effects
Assessment Project
(CEAP)

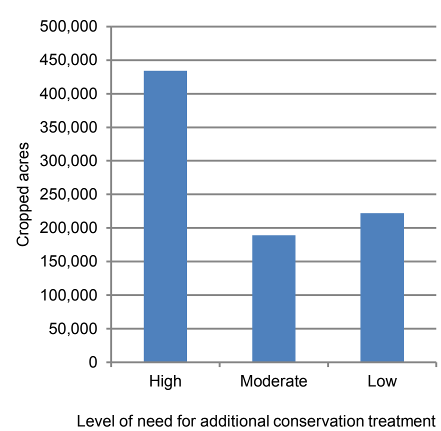
NOVEMBER 2014

Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Delaware River Basin









This page intentionally left blank.

Cover photos by (clockwise from top left) **Tim McCabe, James Luzader, unknown, unknown,** 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. 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).

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.

Natural Resources Conservation Service, USDA

Daryl Lund, **Project Coordinator**, Beltsville, MD, Soil Scientist
Jay D. Atwood, Temple, TX, Agricultural Economist
Joseph K. Bagdon, Amherst, MA, Agronomist and Pest Management Specialist
Jim Benson, Beltsville, MD, Program Analyst (retired)
Jeff Goebel, Beltsville, MD, Statistician (retired)
Kevin Ingram, Beltsville, MD, Agricultural Economist
Mari-Vaughn V. Johnson, Temple, TX, Agronomist
Robert L. Kellogg, Beltsville, MD, Agricultural Economist (retired, Earth Team Volunteer)
Jerry Lemunyon, Fort Worth, TX, Agronomist and Nutrient Management Specialist (retired, Earth Team Volunteer)
Lee Norfleet, Temple, TX, Soil Scientist
Evelyn Steglich, Temple, TX, Natural Resource Specialist

Agricultural Research Service, USDA, Grassland Soil and Water Research Laboratory, Temple, TX

Jeff Arnold, Agricultural Engineer
Mike White, Agricultural Engineer

Blackland Center for Research and Extension, Texas AgriLife Research, Temple, TX

Tom Gerik, Director
Santhi Chinnasamy, Agricultural Engineer
Mauro Di Luzio, Research Scientist
Arnold King, Resource Conservationist
David C. Moffitt, Environmental Engineer
Kannan Narayanan, Agricultural Engineer
Theresa Pitts, Programmer
Xiuying (Susan) Wang, Agricultural Engineer
Jimmy Williams, Agricultural Engineer

University of Massachusetts Extension, Amherst, MA

Stephen Plotkin, Water Quality Specialist

The study was completed under the direction of **David Smith**, Acting Deputy Chief for Soil Science and Resource Assessment, **Michele Laur**, Director for Resource Assessment Division, and **Mike Golden**, **Douglas Lawrence**, **Wayne Maresch, William Puckett,** and **Maury Mausbach,** former Deputy Chiefs for Soil Survey and Resource Assessment, NRCS. Executive support was provided by the current NRCS Chief, **Jason Weller**, and former NRCS Chiefs **Dave White, Arlen Lancaster**, and **Bruce Knight**.

Acknowledgements

The team thanks **Alex Barbarika**, **Rich Iovanna**, and **Skip Hyberg** USDA-Farm Service Agency, for providing data on Conservation Reserve Program (CRP) practices and making contributions to the report; **Harold Coble and Danesha Carley**, North Carolina State University, for assisting with the analysis of the integrated pest management (IPM) survey data; **Dania Fergusson, Eugene Young,** and **Kathy Broussard**, USDA-National Agricultural Statistics Service, for leading the survey data collection effort; **Mark Siemers** and **Todd Campbell**, CARD, Iowa State University, for providing I-APEX support; **NRCS field offices** for assisting in collection of conservation practice data; **Dean Oman**, USDA-NRCS, Beltsville, MD, for geographic information systems (GIS) analysis support; **Melina Ball**, Texas AgriLife Research, Temple, TX, for HUMUS graphics support; **Peter Chen, Susan Wallace, George Wallace, and Karl Musser,** Paradigm Systems, Beltsville, MD, for graphics support, National Resources Inventory (NRI) database support, Web site support, and calculation of standard errors; and many others who provided advice, guidance, and suggestions throughout the project.

The team also acknowledges the many helpful and constructive suggestions and comments by reviewers who participated in the peer review of earlier versions of the report.

Foreword

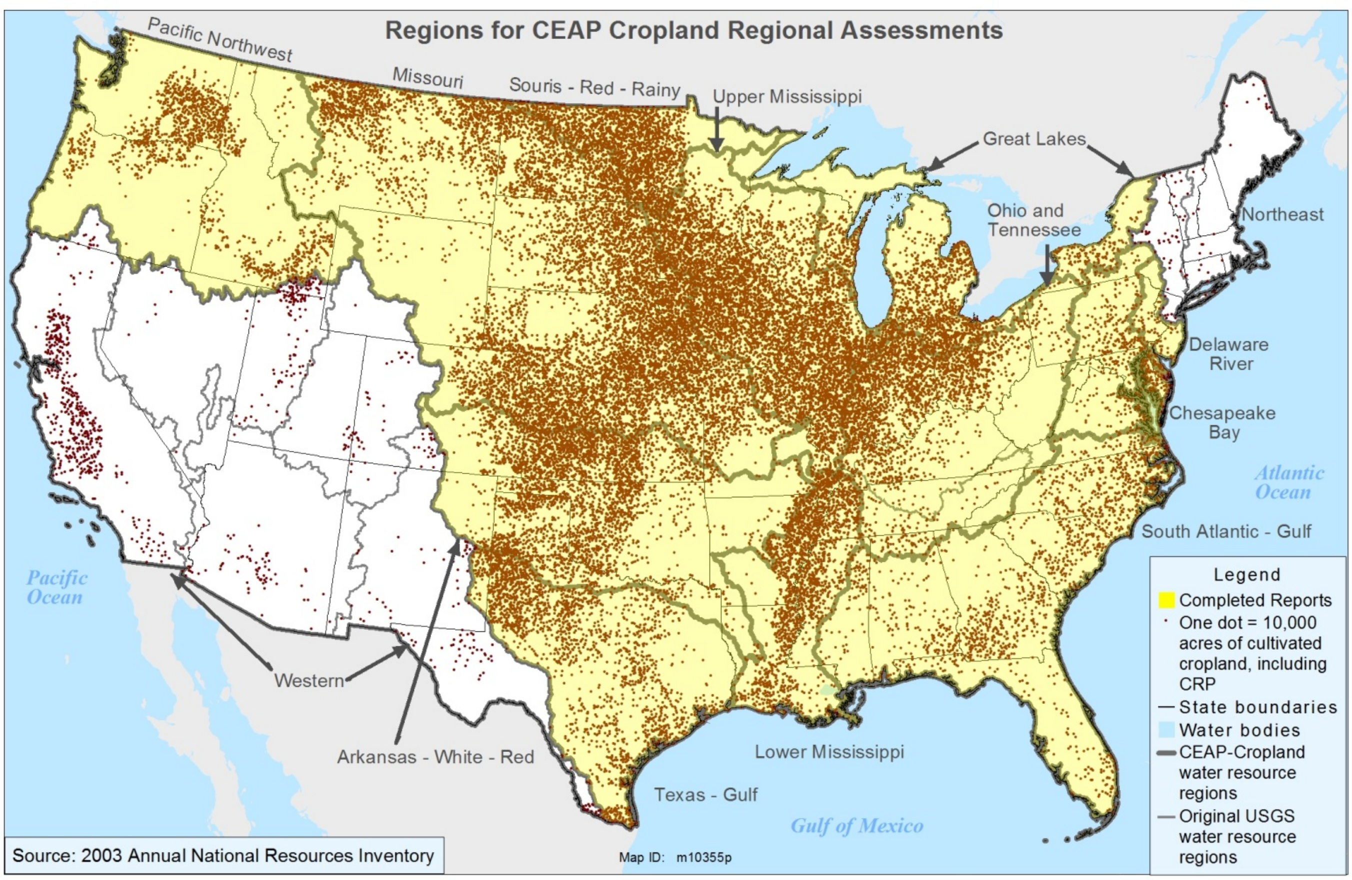
The United States Department of Agriculture has a rich tradition of working with farmers and ranchers to enhance agricultural productivity and environmental protection. Conservation pioneer Hugh Hammond Bennett worked tirelessly to establish a nationwide Soil Conservation Service along with a system 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 also became 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.

The Conservation Effects Assessment Project (CEAP) 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. CEAP 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. CEAP findings have been prepared in a series of 12 reports for the 12 regions shown in yellow in the following map.



Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Delaware River Basin

Contents

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/wps/portal/nrcs/main/national/technical/nra/ceap/pub/. (Go to the "National Assessments: Cropland" section and click on "full list of modeling documentation reports.") Included are the following reports that provide details on the modeling and databases used in this report:

- 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
- Historical Development and Applications of the EPIC and APEX Models
- Adjustment of CEAP Cropland Survey Nutrient Application Rates for APEX Modeling

Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Delaware River Basin

Executive Summary

Agriculture in the Delaware River Basin

The Delaware River Basin consists of the drainage from the Delaware River within the Mid-Atlantic Region, which discharges into the Delaware Bay and then into the Atlantic Ocean. The basin includes parts of Delaware, Maryland, Pennsylvania, New Jersey, and New York. It covers 13,623 square miles (8.7 million acres). Most of the area is forestland (46 percent). Cultivated cropland accounts for only about 13 percent of the area, located mostly in the lower reach of the basin. Other agricultural lands (pasture, hayland, and horticulture) also make up 13 percent of the area, and water and wetlands make up about 13 percent. Urban areas make up 14 percent of the area in the basin; major metropolitan areas include Philadelphia and Allentown, PA, Wilmington, DE, and Trenton, NJ.

The 2007 Census of Agriculture reported about 15,000 farms in the Delaware River Basin. About 63 percent of Delaware River Basin farms primarily raise crops, about 30 percent are primarily livestock operations, and the remaining 6 percent produce a mix of livestock and crops. The value of Delaware River Basin agricultural sales in 2007 was about $2 billion; about 65 percent was from crops and 35 percent was from livestock. Corn, soybeans, and hay are the principal crops grown, accounting for 74 percent of harvested crop acreage in 2007. Wheat is also an important crop in the region.

Focus of CEAP Study Is on Edge-Of-Field Losses from Cultivated Cropland

The study on the Delaware River Basin was designed to—[1]

- quantify the edge-of-field effects of conservation practices commonly used on cultivated cropland in the Delaware River Basin during 2003–06,
- evaluate the need for additional conservation treatment in the region on the basis of edge-of-field losses, and
- estimate the potential gains that could be attained with additional conservation treatment.

The assessment uses a statistical sampling and modeling approach to estimate the effects of conservation practices. 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. Physical process simulation models were used to estimate the effects of conservation practices in use during the period 2003–06. 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. The analysis assumes that structural practices (such as buffers, terraces, and grassed waterways) reported in the farmer survey or obtained from other sources were appropriately designed, installed, and maintained. The assessment was done using a common set of criteria and protocols applied to all regions in the country to provide a systematic, consistent, and comparable assessment at the national level.

Voluntary, Incentives-Based Conservation Approaches Are Achieving Results

Results from the farmer survey show that farmers in the Delaware River Basin have made significant progress in reducing sediment, nutrient, and pesticide losses from farm fields through conservation practice adoption, but results also show that much more could be done to protect farm fields from losses in this region.

---

[1] The Delaware River Basin is the smallest of the 12 CEAP regions included in the full study. Because of the small size of the basin, the scope of the analysis was restricted to the 845,600 cropped acres within the basin, represented by 186 CEAP sample points with farmer survey data. Extensions of the analysis addressed in other regional reports but excluded from this report are: 1) assessment of the edge-of-field effects of enrollment of cropped acres in long-term conserving cover, and 2) model estimates of the effects of conservation practices on reductions in loads delivered to rivers and streams and reductions in instream loads. While restricted in scope, the report provides full documentation of the estimates of conservation treatment needs as reported in the 2011 RCA Appraisal (USDA 2011).

Conservation Practice Use

The farmer survey found, for the period 2003–06, that producers use either residue and tillage management practices or structural practices, or both, on 95 percent of the cropped acres.

- Structural practices for controlling water erosion are in use on 48 percent of cropped acres. Structural practices designed are in use on 64 percent of the acres designated as highly erodible land and 33 percent of the remaining acres.
- Reduced tillage is common in the region; 77 percent of the cropped acres meet criteria for either no-till (32 percent) or mulch till (45 percent). All but 12 percent of the acres have evidence of some kind of reduced tillage on at least one crop in the rotation.

The farmer survey also found that the majority of acres have evidence of some nitrogen or phosphorus management. For example—

- About 4 percent of cropped acres have no nitrogen applied. An additional 62 percent of cropped acres meet criteria for timing of nitrogen applications on all crops in the rotation, 30 percent meet criteria for method of application, and 43 percent meet criteria for rate of application.
- Less than 1 percent of cropped acres have no phosphorus applied. An additional 69 percent of cropped acres meet criteria for timing of phosphorus applications on all crops in the rotation, 52 percent meet criteria for method of application, and 48 percent meet criteria for rate of application.

There was less evidence, however, of ***consistent*** use of appropriate rates, timing, *and* method of nutrient application on each crop in every year of production.

- Appropriate nitrogen application rates, timing of application, and application method for all crops during every year of production are in use on only about 11 percent of cropped acres.
- Good phosphorus management (appropriate rate, timing, and method) is used on 26 percent of the acres during every year of production.
- Only about 12 percent of cropped acres meet nutrient management criteria for both nitrogen and phosphorus management.

Conservation Accomplishments at the Field Level

Compared to a model scenario without conservation practices, field-level model simulations on cropped acres showed that conservation practice use during the period 2003–06 has, on average—

- reduced waterborne sediment loss from fields by 44 percent;
- reduced nitrogen lost with surface runoff (attached to sediment and in solution) by 34 percent;
- reduced nitrogen loss in subsurface flows by 33 percent;
- reduced total phosphorus loss (all loss pathways) from fields by 41 percent; and
- reduced pesticide loss from fields to surface water, resulting in a 27-percent reduction in edge-of-field pesticide risk (all pesticides combined) for humans and a 35-percent reduction for aquatic ecosystems.

In this region, conservation practices on most cropped acres have little effect on soil organic carbon levels. Conservation practice use in the region has resulted in an average annual gain in soil organic carbon of only 37 pounds per acre per year on cropped acres.

Model simulation results indicated that, in spite of the reductions attained with the use of conservation practices, field-level losses remain high for nitrogen in subsurface flows and for soluble phosphorus. Model simulation of additional conservation treatment shows that pairing effective nutrient management practices (consistent use of appropriate rate, form, timing, *and* method of application) with water erosion control practices could reduce nitrogen loss in subsurface flow to low levels for 81 percent of the cropped acres in this region and reduce phosphorus loss to surface water (including soluble phosphorus) to low levels for 90 percent of the cropped acres.

If the 2003–06 level of conservation practice use is not maintained, some of these gains will be lost.

> The evaluation of conservation practices and associated estimates of sediment, nitrogen, and pesticide losses from farm fields are based on practice use derived from a farmer survey conducted during the years 2003–06. Since then, implementation of the 2008 Farm Bill expanded conservation funding in the region. As a result, farmers have increased the use of appropriate nutrient management, cover crops, integrated pest management, and other practices. It is therefore likely that the effects of conservation practice use within this region are greater today than determined during this study.

Opportunities Exist to Further Reduce Sediment and Nutrient Losses from Cultivated Cropland

The assessment of conservation treatment needs identified significant opportunities to further reduce contaminant losses from farm fields. The study found that 51.3 percent of cropped acres (434,212 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 or nutrients. These 434,212 acres lose (per acre per year, on average) 4.4 tons of sediment by water erosion, 7.0 pounds of phosphorus, and 62 pounds of nitrogen.

An additional 22.4 percent of cropped acres (189,276 acres) have a **moderate** need for additional conservation treatment. These 189,276 acres lose (per acre per year, on average) 0.4 ton of sediment by water erosion, 2.0 pounds of phosphorus, and 52 pounds of nitrogen.

The remaining 222,113 cropped acres (26.3 percent) have a **low** need for additional treatment and are considered to be adequately treated. These 222,113 acres lose (per acre per year, on average) 0.4 ton of sediment by water erosion, 1.5 pounds of phosphorus, and 18 pounds of nitrogen. While gains can be attained by adding conservation practices to some of these acres with a low treatment need, additional conservation treatment would reduce average field losses by only a small amount.

Both erosion control and nutrient management are critical conservation concerns in this region. Some acres need additional treatment for erosion control and runoff, other acres need additional treatment only for nitrogen leaching (one-third of the undertreated acres), and other acres need treatment for both. Twenty-eight percent of undertreated acres need additional treatment for sediment loss and/or nitrogen or phosphorus loss with surface water runoff but do not need additional treatment for nitrogen leaching. About one-fourth of the undertreated acres need treatment for all four resource concerns. Most of the undertreated acres need additional treatment for multiple resource concerns.

Model simulations show that adoption of additional erosion control and nutrient management practices on the 623,487 acres with a **high** or **moderate** treatment need would, compared to the 2003–06 baseline, further reduce edge-of-field—

- sediment loss in the region by an average of 88 percent,
- losses of nitrogen with surface runoff by an average of 68 percent,
- losses of nitrogen in subsurface flows by an average of 41 percent, and
- losses of phosphorus (sediment-attached and soluble) by an average of 62 percent.

Emerging technologies not evaluated in this study promise to provide even greater conservation benefits once their use becomes more widespread. These include—

- innovations in implement design to enhance precise nutrient application and placement, including variable rate technologies and improved manure application equipment;
- enhanced-efficiency nutrient application products such as slow or controlled-release fertilizers (for example: polymer-coated products, sulfur-coated products, etc.) and nitrogen stabilizers (for example: urease inhibitors, and nitrification inhibitors);
- drainage water management that controls discharge of drainage water and treats contaminants, thereby reducing the levels of nitrogen and even some soluble phosphorus loss;
- constructed wetlands receiving surface water runoff and drainage water from farm fields prior to discharge to streams and rivers; and
- improved crop genetics that increase yields without increasing nutrient inputs.

Comprehensive Conservation Planning and Targeting Enhance Effectiveness and Efficiency of Conservation Program Implementation

A comprehensive conservation planning process is required to identify the appropriate combination of nutrient management techniques and enhanced soil erosion control practices needed to simultaneously address soil erosion, soluble phosphorus losses, nitrogen and phosphorus losses in surface runoff, *and* loss of nitrogen in subsurface flows for each field. A field with adequate conservation practice use will have a suite of practices that addresses all the specific inherent vulnerability factors that determine the potential for sediment, nutrient, and pesticide losses through the dominant loss pathways.

Not all acres require the same level of 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 on these acres. 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 permeable 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.

Moreover, model simulations show that treatment of erosion alone in this region can sometimes exacerbate the nitrogen leaching problem because reducing surface water runoff increases infiltration and, therefore, movement of soluble nitrogen into subsurface flow pathways. Soil erosion control practices are effective in reducing the loss of nitrogen in surface runoff, but for 12 percent of cropped acres the re-routing of surface water runoff to subsurface flow along with incomplete nutrient management results in a net increase in total nitrogen loss from the field.

These model simulations also showed that a *suite of practices* that includes both soil erosion control and complete and consistent use of nutrient management—appropriate rate, form, timing, *and* method of application—is often *required* to reduce both sediment and nutrient losses from farm fields to acceptable levels simultaneously. Treatment with combinations of soil erosion control practices and nutrient management also makes applied nutrients more available for use by crops.

Targeting program funding and technical assistance for accelerated treatment of acres with the most critical need for additional treatment is the most efficient way to reduce agricultural sources of contaminants from farm fields. In this region, 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 per-acre sediment and nutrient losses by much more than treatment of acres with a **moderate** conservation treatment need. Even greater efficiencies are realized when acres with a **high** need for additional treatment are compared to per-acre benefits for acres with a **low** need for additional treatment. For example, model simulations of additional treatment in the Delaware River Basin demonstrated that sediment loss would be reduced by an average of 4.1 tons per acre per year on the 434,212 acres with a **high** need for additional treatment, compared to 0.34-0.35 ton per acre per year for additional treatment of the 189,276 acres with a **moderate** need for additional treatment and the 222,113 acres with a **low** need for additional treatment.

Total nitrogen loss (all loss pathways) would be reduced by an average of 32 pounds per acre per year on the 434,212 critical undertreated acres and 27 pounds per acre for the 189,276 undertreated acres with a moderate need for treatment, compared to a reduction of only 2 pounds per acre for the remaining 222,113 acres.

Total phosphorus loss would be reduced by an average of 4.9 pounds per acre per year on the 434,212 critical undertreated acres, compared to a reduction of only 0.7 pounds per acre for the 189,276 undertreated acres with a moderate need for treatment and for the 222,113 acres with a low need for additional treatment.

Effects of Conservation Practices on Ecological Conditions Are Beyond the Scope of This Study

Ecological outcomes are not addressed in this report, nor were the estimates of conservation treatment needs specifically derived to attain Federal, State, or local water quality goals within the region.

Ecosystem impacts related to water quality are specific to each water body. Water quality goals also depend on the designated uses for each water body. In order to understand the effects of conservation practices on water quality in streams and lakes, it is first necessary to understand what is happening in the receiving waters and then evaluate whether the practices are having the desired effect on the current state of that aquatic ecosystem.

The regional scale and statistical design of this study precludes these kinds of assessments.

The primary focus of this report is on losses of potential pollutants from farm fields and prospects for attaining further loss reductions with additional soil erosion control and nutrient management practices. Conservation treatment needs were estimated to achieve "full treatment" from the field-level perspective, rather than to reduce instream loads to levels adequate for designated water uses. The simulated treatment levels were designed to minimally affect crop yields and maintain regional production capacity for food, feed, fiber, forage, and fuel.

From this perspective, a field with adequate conservation treatment will have combinations of practices that address all the specific inherent vulnerability factors that determine the potential for sediment, nutrient, and pesticide losses. For purposes of this report, "full treatment" consists of a suite of practices that—

- *avoid* or limit the potential for contaminant losses 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.

This field-based concept of "full conservation treatment" will likely be sufficient to protect water quality for some environmental settings. For more sensitive environmental settings, however, it may be necessary to adopt even stricter management criteria and techniques such as widespread use of cover crops, drainage water management, conservation rotations, or emerging production and conservation technologies. In some cases, attainment of water quality goals may even require watershed-scale solutions, such as sedimentation basins, wetland construction, streambank restoration, or an increased proportion of acres in long-term conserving cover.

Chapter 1
Land Use and Agriculture in the Delaware River Basin

Land Use

The Delaware River Basin consists of all land draining to the Delaware River within the Mid-Atlantic Region, discharging into the Delaware Bay and then into the Atlantic Ocean. The basin includes parts of Delaware, Maryland, Pennsylvania, New Jersey, and New York. It covers 13,623 square miles (8.7 million acres).

Cultivated cropland accounts for about 13 percent of the area (table 1, fig. 1). (Cultivated cropland includes land in long-term conserving cover, which is represented by acres enrolled in the General Sign-up of the Conservation Reserve Program [CRP].) Pastureland accounts for 8 percent and hayland (not in rotation with crops) accounts for 4 percent. Forestland makes up 46 percent of the land area, found mostly in the upper portion of the drainage area. Water and wetlands make up 13 percent of the area. Rangeland, horticulture, and other non-urban lands make up about 2 percent of the area.

Urban areas make up 14 percent of the area in the basin (16 percent excluding water). The major metropolitan areas are Philadelphia and Allentown, PA, Wilmington, DE, and Trenton, NJ.

Table 1. Land cover and use in the Delaware River Basin

Land use	Acres*	Percent of area (including water)	Percent of land base (excluding water)
Cultivated cropland and land enrolled in the CRP General Signup**	1,103,941	13	14
Hayland not in rotation with crops	316,075	4	4
Pastureland not in rotation with crops	660,227	8	8
Rangeland—grass	12,884	<1	<1
Rangeland—brush	20,242	<1	<1
Horticulture	48,341	1	1
Forestland			
Deciduous	3,365,140	39	42
Evergreen	304,800	3	4
Mixed	389,213	4	5
Urban	1,254,561	14	16
Wetlands			
Forested	352,319	4	4
Non-Forested	163,098	2	2
Barren	76,941	1	1
Subtotal	8,067,783	93	100
Water	650,774	7	
Total	8,718,557	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 based on the NRI-CEAP sample because of differences in data sources and estimation procedures. Acres enrolled in the CRP General Signup are used to represent land in long-term conserving cover and are included here as part of cultivated cropland.
**Includes hayland and pastureland in rotation with crops.

Agriculture

The 2007 Census of Agriculture reported about 15,000 farms in the Delaware River Basin (table 2). Land on farms, which can include any of the land use categories shown in table 1 except urban and water, was about 1.7 million acres, representing 20 percent of the area within the region. According to the 2007 Census of Agriculture, the value of Delaware River Basin agricultural sales in 2007 was about $2 billion. About 65 percent was from crops and 35 percent was from livestock.

About 63 percent of Delaware River Basin farms primarily raise crops, about 30 percent are primarily livestock operations, and the remaining 6 percent produce a mix of livestock and crops (table 3).

Most of the farms are small. About 96 percent of farms have less than 500 acres, 4 percent have 500–2,000 acres, and less than 1 percent of the farms have more than 2,000 acres (table 3). In terms of 2007 gross sales, 75 percent had less than $50,000 in total farm sales and 14 percent had $50,000–$250,000 in total farm sales (table 3). Farms with total agricultural sales greater than $250,000 accounted for 11 percent of the farms in the region. About 49 percent of the principal farm operators indicated that farming was their principal occupation.

Crop production

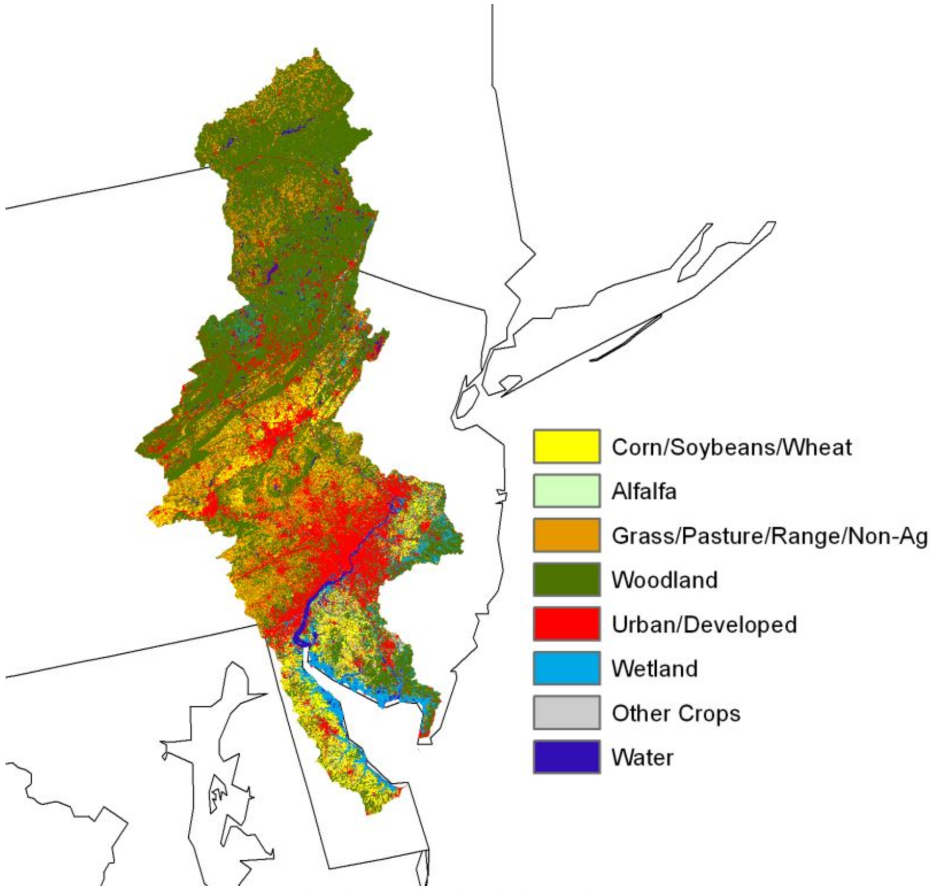
The Delaware River Basin accounted for about $1.3 million in crop sales in 2007 (table 2). Corn, soybeans, and hay are the principal crops grown, accounting for 74 percent of harvested crop acreage in 2007. Wheat is also an important crop in the region. In 2007, about 10 percent of harvested acres were irrigated.

Commercial fertilizers and pesticides are widely used throughout the region (table 2). In 2007, about 773,000 acres of cropland were fertilized, 613,000 acres of cropland and pasture were treated with chemicals for weed control, and 350,000 acres of cropland were treated for insect control. About 194,000 acres had manure applied in 2007.

Statistics for the Delaware River Basin reported in table 2 are for the year 2007 as reported in the Census of Agriculture. For some characteristics, different acre estimates are reported in subsequent sections of this report based on the NRI-CEAP sample. Estimates based on the NRI-CEAP sample are for the time period 2003–06. See chapter 2 for additional aspects of estimates based on the NRI-CEAP sample.

For example, the Census of agriculture reports that about 10 percent of harvested acres were irrigated in 2007 (table 2). Based on the NRI-CEAP sample for 2003-06, about 13 percent of cropped acres in the region had the facilities and equipment to irrigate the sample field in one or more of the four survey years. The amount of acres that receive irrigation water varies from year to year.

Figure 1. Land cover in the Delaware River Basin



Source: National Agricultural Statistics Service (NASS 2007).

Livestock operations

Livestock production in the region is dominated by dairy and poultry. Poultry operations in the region produced $298 million in sales in 2007 (table 2) and accounted for 15 percent of total agricultural sales in the region. Dairy production totaled $255 million, accounting for 13 percent of total agricultural sales in the region.

Cattle and other pastured livestock are important in the region as well. Of the 286,000 livestock animal units in the region in 2007, 102,000 animal units were cattle, horses, sheep, and goats, excluding fattened cattle and dairy cows. (An animal unit is 1,000 pounds of live animal weight, calculated as a yearly average for each farm using information reported in the 2007 Census of Agriculture.) Poultry animal units totaled about 52,000 and dairy cow animal units totaled about 101,000.

Based on livestock populations on farms as reported in the 2007 agricultural census, about 1,500 of the farms in the region (10 percent) could potentially be defined as animal feeding operations (AFOs) (table 3). AFOs are livestock operations typically with confined poultry, swine, dairy cattle, or beef cattle. Less than 200 of the livestock operations are relatively large, with livestock numbers in 2007 above the EPA minimum threshold for a medium concentrated animal feeding operation (CAFO). Of these, about 50 meet livestock population criteria for a large CAFO.

An additional 1,450 farms have significant numbers of pastured livestock (10 percent of farms).

Table 2. Profile of farms and land in farms in the Delaware River Basin, 2007

Characteristic	Value
Number of farms	15,177
Acres on farms	1,704,158
Average acres per farm	112
Cropland harvested, acres	1,032,807
Cropland used for pasture, acres	69,015
Cropland on which all crops failed, acres	10,280
Cropland in summer fallow, acres	5,423
Cropland idle or used for cover crops, acres	54,000
Woodland pastured, acres	26,067
Woodland not pastured, acres	255,294
Permanent pasture and rangeland, acres	131,967
Other land on farms, acres	119,305
Principal crops grown	
Field corn for grain harvested, acres harvested	295,569
Soybeans harvested, acres harvested	212,290
Wheat harvested, sum acres harvested	79,655
Tame and wild hay harvested, acres harvested	190,038
Alfalfa hay, acres harvested	66,854
Irrigated harvested land, acres	101,045
Cropland fertilized, acres	772,753
Land treated for insects on hay or other crops, acres	349,525
Land treated for nematodes in crops, acres	17,947
Land treated for diseases in crops and orchards, acres	63,392
Land treated for weeds in crops and pasture, acres	613,060
Acres on which manure was applied	194,403
Total grains and oilseeds sales, million dollars	186
Total vegetable, melons sales, million dollars	172
Total nursery, greenhouse, and floriculture sales, million dollars	845
Total other crops and hay sales, million dollars	109
Total crop sales, million dollars	1,312
Total dairy sales, million dollars	255
Total hog and pig sales, million dollars	29
Total poultry and eggs sales, million dollars	298
Total cattle sales, million dollars	58
Total sheep, goats, and their products sales, million dollars	2
Total horses, ponies, and mules sales, million dollars	30
Total other livestock sales, million dollars	27
Total livestock sales, million dollars	699
Animal units on farms	
All livestock types	285,989
Swine	19,011
Dairy cows	101,362
Fattened cattle	9,051
Other cattle, horses, sheep, goats	102,308
Chickens, turkeys, and ducks	51,865
Other livestock	2,392

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).

Table 3. Characteristics of farms in the Delaware River Basin, 2007

	Number of farms	Percent of farms in Delaware River Basin
Farming primary occupation	7,420	49
Farm size:		
<50 acres	9,240	61
50–500 acres	5,283	35
500–2,000 acres	603	4
>2,000 acres	51	<1
Farm sales:		
<$10,000	8,345	55
$10,000–50,000	2,994	20
$50,000–250,000	2,121	14
$250,000–500,000	772	5
>$500,000	945	6
Farm type:		
Crop sales make up more than 75 percent of farm sales	9,591	63
Livestock sales make up more than 75 percent of farm sales	4,624	30
Mixed crop and livestock sales	962	6
Farms with no livestock sales	6,730	44
Farms with few livestock or specialty livestock types	5,518	36
Farms with pastured livestock and few other livestock types	1,453	10
Farms with animal feeding operations (AFOs)*	1,476	10

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. An animal unit is 1,000 pounds of live animal weight, calculated as a yearly average for each farm using information reported in the 2007 Census of Agriculture.

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). Each water resource region is designated with a 2-digit Hydrologic Unit Code (HUC), which is further divided into 4-digit subregions, 6-digit accounting units, and then into 8-digit cataloging units. The Delaware River Basin is made up of two 6-digit accounting units—

- the Upper Delaware River (code 020401), and
- the Lower Delaware River (code 020402).

Cultivated cropland is spread throughout most of the region but is not a dominant land use (table 4 and fig. 2). Seventy percent of the cultivated cropland in the basin is in the Lower Delaware River drainage (code 020402), where cultivated cropland accounts for 18 percent of the watershed area. Only 8 percent of the area in the Upper Delaware River drainage (code 020401) is cultivated cropland.

Cultivated cropland reported in tables 1 and 4 includes land in long-term conserving cover, which represents about 17 percent of the cultivated cropland acres in this region, shown in table 4.

Table 4. Cultivated cropland use in the two 6-digit cataloging units that make up the Delaware River Basin

Accounting Unit	Total area (acres)	Cultivated cropland (acres)*	Percent cultivated cropland in 6-digit accounting unit	Percent of cultivated cropland in Delaware River Basin	Percent of cultivated cropland acres in long-term conserving cover
Upper Delaware River (code 020401)	4,394,980	330,064	8	30	0
Lower Delaware River (code 020402)	4,323,577	773,877	18	70	24
Total	8,718,557	1,103,941	13	100	17

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.

Figure 2. Percent cultivated cropland, including land in long-term conserving cover, for the two 6-digit accounting units in the Delaware River Basin

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 in 2003–06;
- 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 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.

Sampling and Modeling Approach

The assessment uses a statistical sampling and modeling approach to estimate the environmental effects and benefits of conservation practices on cropped acres.

- A subset of 186 National Resources Inventory (NRI) sample points provides a statistical sample that represents the diversity of soils and other conditions for cropped acres in the Delaware River Basin. 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 each of the 186 cropped 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.

For purposes of this report, cropped acres include land in row crops or close-grown crops (such as wheat and other small grain crops), and hay and pasture in rotation with row crops and close-grown crops. Cropped acres do not include agricultural land that has been in hay, pasture, or horticulture for 4 or more consecutive years, corresponding to the cultivated cropland definition used in the NRI.

The scope of this report on the Delaware River Basin is restricted to evaluating the effects of conservation practices, as described above, only for the edge-of-field losses for cropped acres.

The Delaware River Basin is the smallest of the 12 CEAP regions included in the study. It also has the fewest NRI-CEAP sample points, which restricts the scope of analysis compared to reports for other CEAP regions in two major ways.

1. In other CEAP reports, estimates were made of edge-of-field losses of sediment and nutrients for land in long-term conserving cover, as represented by NRI sample points designated as acres enrolled in the CRP General Signup. In the Delaware River Basin, however, only two NRI sample points designated as CRP acres were available for modeling within the basin. Consequently, model results for land in long term conserving cover could not be reliably reported for this region.
2. Also in other CEAP reports, a watershed model (the Soil and Water Assessment Tool, called SWAT) 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. Because the Delaware River Basin is represented by only two 6-digit accounting units, the area is too small for reliable reporting of loads delivered to rivers and streams from cultivated cropland, which includes land in long-term conserving cover. Without reliable estimates of loads from land in long-term conserving cover, estimated loads delivered to rivers and streams from cultivated cropland cannot be made. Consequently, model estimates for the effects of conservation practices on reductions in loads delivered to rivers and streams and reductions in instream loads could not be presented in this report.

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 baseline conservation condition scenario.

The effects of conservation practices are obtained by taking the difference in model results between the two scenarios (fig. 3). 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.[2] 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. 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, Goebel and Kellogg 2002).

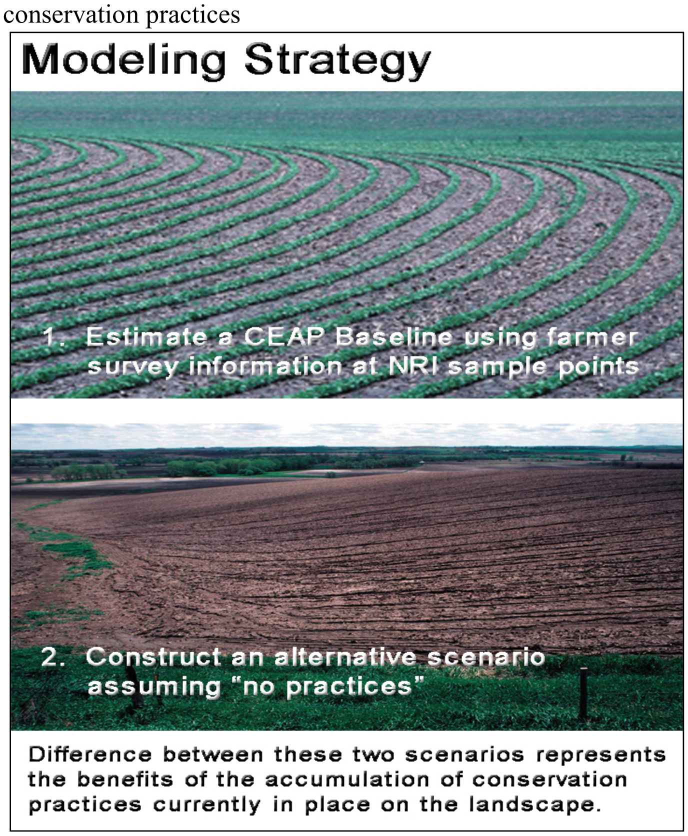
The NRI and the CEAP Sample

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).

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.

Figure 3. Modeling strategy used to assess effects of conservation practices



[2] This modeling strategy is analogous 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, and change with changes in conservation practice use. 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 representation of a "no-practice" scenario where C=1 represents smooth-tilled continuous fallow and P=1 represents no supporting practices.

NRCS has 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.*[3] 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.

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, 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 the crops grown were uncommon and model parameters for crop growth were not available. The national NRI-CEAP usable sample consists of about 18,700 NRI points representing cropped acres.

The NRI-CEAP Cropland Survey

A farmer survey—the NRI-CEAP Cropland Survey—was conducted to obtain the additional information needed for modeling the 186 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 data collection effort, NRCS field offices provided information on the practices specified in conservation plans for the CEAP sample points.

The data collection process was spread 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 4 years.

Estimated Acres

Acres reported using the CEAP sample are "estimated" acres because of the uncertainty associated with the statistical sample. For example, the 95-percent confidence interval for the estimate of 845,600 cropped acres in the region has a lower bound of 734,191 acres and an upper bound of 957,009 acres. (The lower bound is the estimate minus the margin of error and the upper bound is the estimate plus the margin of error.) The range of this confidence interval in percentage terms exceeds that for other CEAP regions because of the small sample size available for the Delaware River Basin.

Estimated acres and confidence intervals are shown by cropping systems in table 5. Cropping systems were defined on the basis of the crops grown at CEAP sample points over the 3 years that information was obtained on farming activities at each sample point. Statistical sample weights for each sample point were derived from the NRI crop history at each sample point so as to approximate acres reported in the 2003 NRI for similar cropping systems at the 4-digit HUC level. (Cropping system acres were only one of several factors taken into account in deriving the acreage weights for each sample point.)

Rotations that include corn and/or soybeans are the dominant cropping systems in this region (table 5). Cropping systems that include hay are also important.

Margins of error for a selection of other estimated crop acres used in this report are presented in appendix A.

[3] For more information on the NRI sample design, see www.nrcs.usda.gov/technical/NRI/.
[4] Information about the CEAP sample design is in the documentation report "NRI-CEAP Cropland Survey Design and Statistical Documentation;" see page 5.
[5] The surveys, enumerator instructions, and other documentation can be found at http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/ceap/pub/.

Table 5. Estimated crop acres for cropping systems in the Delaware River Basin

Cropping system	Number of CEAP samples	Estimated acres	Percent of total	95-percent confidence interval Lower bound (acres)	Upper bound (acres)
Corn and soybean only	57	226,591	27	151,268	301,914
Corn and soybean with close grown crops	39	158,700	19	76,484	240,916
Corn only	25	117,327	14	58,598	176,056
Corn with close grown crops	11	71,486	8	23,107	119,865
Soybean only	15	65,764	8	34,882	96,646
Vegetables or tobacco with or without other crops	13	53,235	6	9,315	97,155
Hay-crop mix	15	99,983	12	55,271	144,695
Remaining crop mixes	11	52,514	6	13,480	91,548
Total	186	845,600	100	734,191	957,009

Note: Estimates are from the NRI-CEAP Cropland Survey.

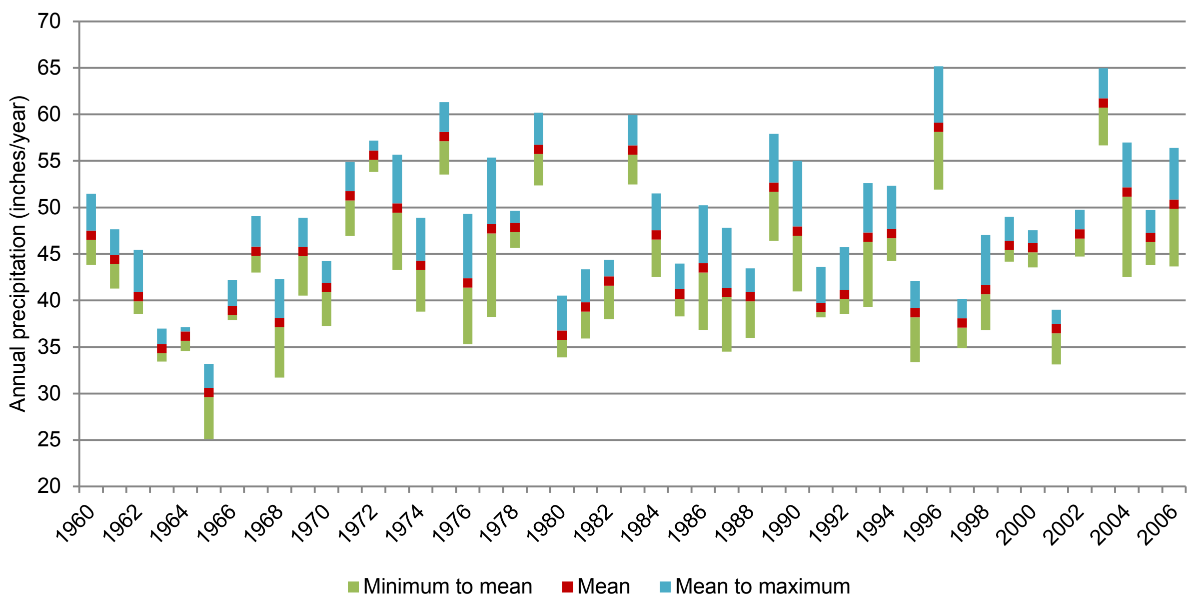
Simulating the Effects of Weather

Weather is the predominant factor determining the loss of soil, nitrogen, phosphorus, and pesticides from farm fields, and has a big influence on the effectiveness 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 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).

Annual precipitation over the 47-year simulation averaged about 45 inches for cropped acres in this region. However, annual precipitation varied substantially in the model simulations, both within the region and from year to year, as shown in figure 4. Year-to-year variability is especially pronounced—the average annual precipitation amount (representing all cropped acres) ranged over the 47 years from 30 inches in 1965 to 61 inches in 2003.

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 shown in figure 4.

Figure 4. Mean, minimum, and maximum levels of annual precipitation used in the model simulations for cropped acres in the Delaware River Basin



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

This study assesses the use and effectiveness of conservation practices in the Delaware River Basin 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 and annual practices, defined as follows.

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 conducted as part of the crop production system each year. These practices are designed primarily to promote soil quality, reduce in-field erosion, increase groundwater recharge, 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.

Historical Context for Conservation Practice Use

The use of conservation practices in the Delaware River Basin 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 stripcropping) 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.

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

The conservation practice information collected during the study was used to assess the extent of conservation practice use in the Delaware River Basin. Key findings are the following:

- Structural practices for controlling water erosion are in use on 48 percent of cropped acres. Structural practices designed to control water erosion are in use on 64 percent of the acres designated as highly erodible land and 33 percent of the remaining acres.
- Reduced tillage is common in the region; 77 percent of the cropped acres meet criteria for either no-till (32 percent) or mulch till (45 percent). All but 12 percent of the acres had evidence of some kind of reduced tillage on at least one crop in the rotation.
- About 25 percent of cropped acres are gaining soil organic carbon.
- Producers use either residue and tillage management practices or structural practices, or both, on 95 percent of cropped 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.
    - About 4 percent of cropped acres have no nitrogen applied. An additional 62 percent of cropped acres meet criteria for timing of nitrogen applications on all crops in the rotation, 30 percent meet criteria for method of application, and 43 percent meet criteria for rate of application.
    - Less than 1 percent of cropped acres have no phosphorus applied. An additional 69 percent of cropped acres meet criteria for timing of phosphorus applications on all crops in the rotation, 52 percent

meet criteria for method of application, and 48 percent meet criteria for rate of application.
    - 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 11 percent of cropped acres.
    - Good phosphorus management practices (appropriate rate, timing, and method) are in use on 26 percent of the acres on all crops during every year of production.
    - Only about 12 percent of cropped acres meet nutrient management criteria for both nitrogen and phosphorus management.
- During the 2003–06 period of data collection, cover crops were used on 4 percent of the acres in the region.
- The Integrated Pest Management (IPM) indicator showed that about 16 percent of the acres were being managed with a high level of IPM.

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 types of 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 aerial 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. These practices are found on about 38 percent of the cropped acres in the region, including 58 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 19 percent of the cropped acres have one or more of these practices, including 26 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 6 percent of all cropped acres in the region (table 6).

Overall, about 48 percent of the cropped acres in the Delaware River Basin are treated with one or more water erosion control structural practices (table 6). The treated percentage for highly erodible land acres is higher—64 percent.

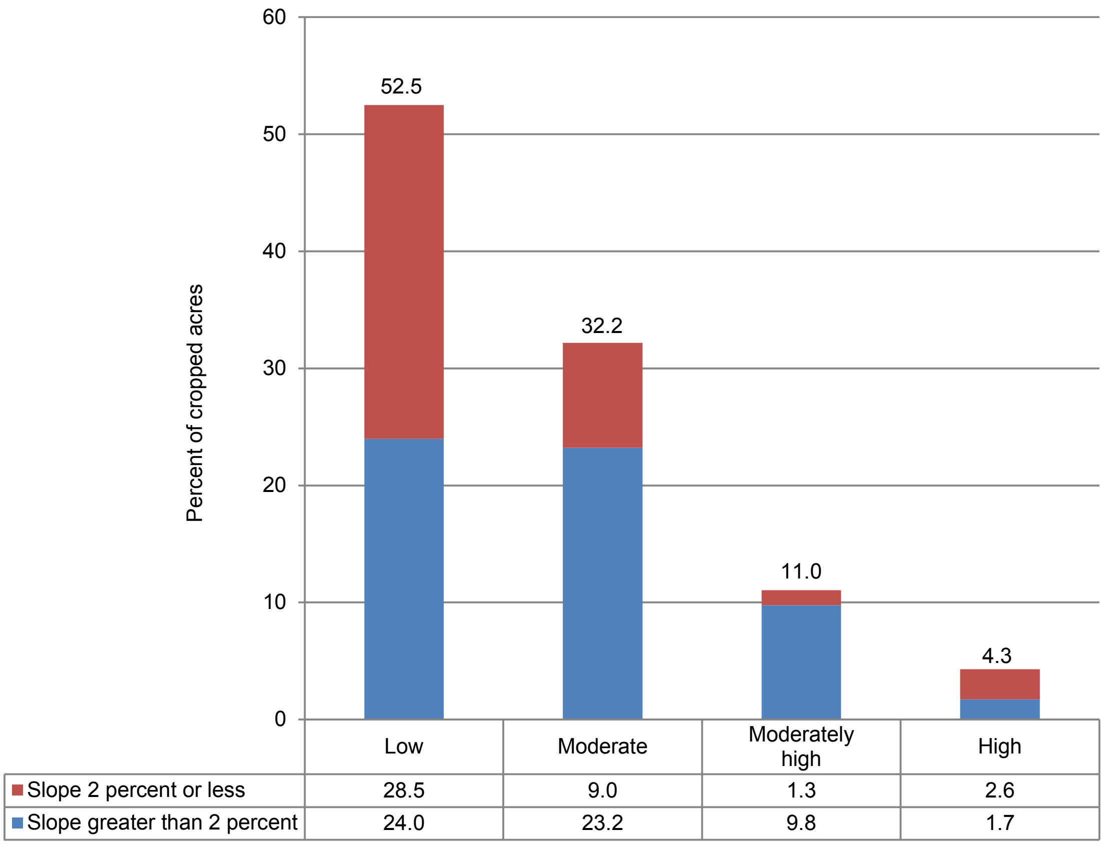
At each sample point, structural conservation practices for water erosion control were determined to be providing either a high, moderately high, moderate, or low level of treatment according to criteria presented in figure 5. Only about 4 percent of cropped acres in the region have a high level of treatment (combination of edge-of-field buffering or filtering and at least one in-field structural practice). About 52 percent of the acres have a low treatment level for structural practices, which indicates that these acres do not have any structural practices for water erosion control. About 32 percent of the acres have a moderate treatment level for structural practices. However, 41 percent of cropped acres in this region have slopes less than 2 percent, including many that 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 undertreated for water erosion control in chapter 5.)

Table 6. Structural conservation practices in use for the baseline conservation condition, Delaware River Basin

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	19	58	38
Concentrated flow control practices	Grassed waterways, grade stabilization structures, diversions, other structures for water control	13	26	19
Edge-of-field buffering and filtering practices	Riparian forest buffers, riparian herbaceous buffers, filter strips	6	5	6
One or more water erosion control practices	Overland flow, concentrated flow, or edge-of-field practice	33	64	48
Wind erosion control practices	Windbreaks/shelterbelts, cross wind trap strips, herbaceous windbreak, hedgerow planting	7	6	7

Note: About 48 percent of cropped acres in the Delaware River Basin 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 5. Percent of cropped acres at four conservation treatment levels for structural practices, baseline conservation condition, Delaware River Basin



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.

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. About 7 percent of the cropped acres in the region are treated for wind erosion using structural practices (table 6).

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. Model outcomes affected by tillage practices, such as erosion and runoff, were determined based on APEX processes of the daily tillage activities as reported in the survey.

The Soil Tillage Intensity Rating (STIR) was used for tillage intensity and gains or losses in soil organic carbon (based on model simulation results) were used as an indicator of residue management.

STIR values represent the soil disturbance intensity, which was estimated for each crop at each sample point.[6] 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.[7]

Overall, 77 percent of cropped acres in the Delaware River Basin meet the tillage intensity rating for either no-till or mulch till (table 7). About 32 percent meet the criteria for no-till, including 37 percent of the HEL. About 45 percent meet the tillage intensity criteria for mulch till. About 11 percent of cropped acres do not meet criteria for mulch till or no-till but have reduced tillage on some crops in the rotation. Only 12 percent of the acres are conventionally tilled for all crops in the rotation.

To evaluate the use of residue and tillage management practices, practice use was classified as high, moderately high, moderate, or low for each sample point according to criteria presented in figure 6. (These residue and tillage management treatment levels were combined with the use of structural practices to estimate conservation treatment levels for water erosion control in chapter 5.) The high and moderately high treatment levels represent the 20.8 percent of cropped acres that meet tillage intensity criteria for either no-till or mulch till and are gaining soil organic carbon.

The high treatment level, representing 17.2 percent of cropped acres, includes only those acres with gains in soil organic carbon and where the tillage intensity criteria are met for *each* crop in the rotation. About 3.6 percent of cropped acres have a moderately high treatment level, where the *average annual* tillage intensity meets criteria for mulch till or no-till and the crop rotation is gaining soil organic carbon.

The bulk of the cropped acres—69.2 percent—have a moderate level of treatment. Most of these acres meet tillage intensity for no-till or mulch till but are losing soil organic carbon. Other acres have reduced tillage but do not meet criteria for no-till or mulch till, or they are gaining soil organic carbon but tillage intensity exceeds criteria for mulch till (fig. 6).

About 10 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.

Structural practices and residue and tillage management practices influence losses of sediment, nutrients, and pesticides due to water erosion. Most of the cropped acres (95 percent) in the Delaware River Basin have one or both of these types of water erosion control practices (table 8). About 38 percent meet tillage intensity for no-till or mulch till *and* have structural practices, including 49 percent of HEL. About 39 percent of cropped acres meet tillage criteria for no-till or mulch till without structural practices in use. Only 7 percent have structural practices without any kind of residue or tillage management (table 8).

Conservation Crop Rotation

In the Delaware River Basin, crop rotations that meet NRCS criteria for conservation cropping (NRCS practice code 328) are used on about 66 percent of the cropped acres. This practice consists of growing different crops in a planned rotation to manage nutrient and pesticide inputs, enhance soil quality, or reduce soil erosion. Including a legume, hay, or 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 effects of conservation crop rotations, but the benefits of conservation crop rotation practices could not be assessed quantitatively in this study. 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 mono-cropping systems, which would require arbitrary decisions about which crops to simulate at each sample point to preserve the level of regional production.

[6] Percent residue cover was not used to evaluate no-till or mulch till because this criterion is not included in the current NRCS practice standard for Residue and Tillage Management. Residue is, however, factored into erosion and runoff estimates in APEX.

[7] STIR values in combination with carbon trends are in line with the use of the Soil Conditioning Index (SCI), which approximates the primary criteria for NRCS residue management standards. The NRCS practice standard, as applied at the field, may include other considerations to meet site specific resource concerns that are not considered in this evaluation.

Table 7. Residue and tillage management practices for the baseline conservation condition based on STIR ratings for tillage intensity and model output on carbon gain or loss, Delaware River Basin

Residue and tillage management practice in use	Percent of non-HEL	Percent of HEL	Percent of all cropped acres
All cropped acres			
Average annual tillage intensity for crop rotation meets criteria for no-till*	28	37	32
Average annual tillage intensity for crop rotation meets criteria for mulch till**	53	36	45
Reduced tillage on some crops in rotation but average annual tillage intensity greater than criteria for mulch till	8	14	11
Continuous conventional tillage in every year of crop rotation***	11	12	12
Total	100	100	100

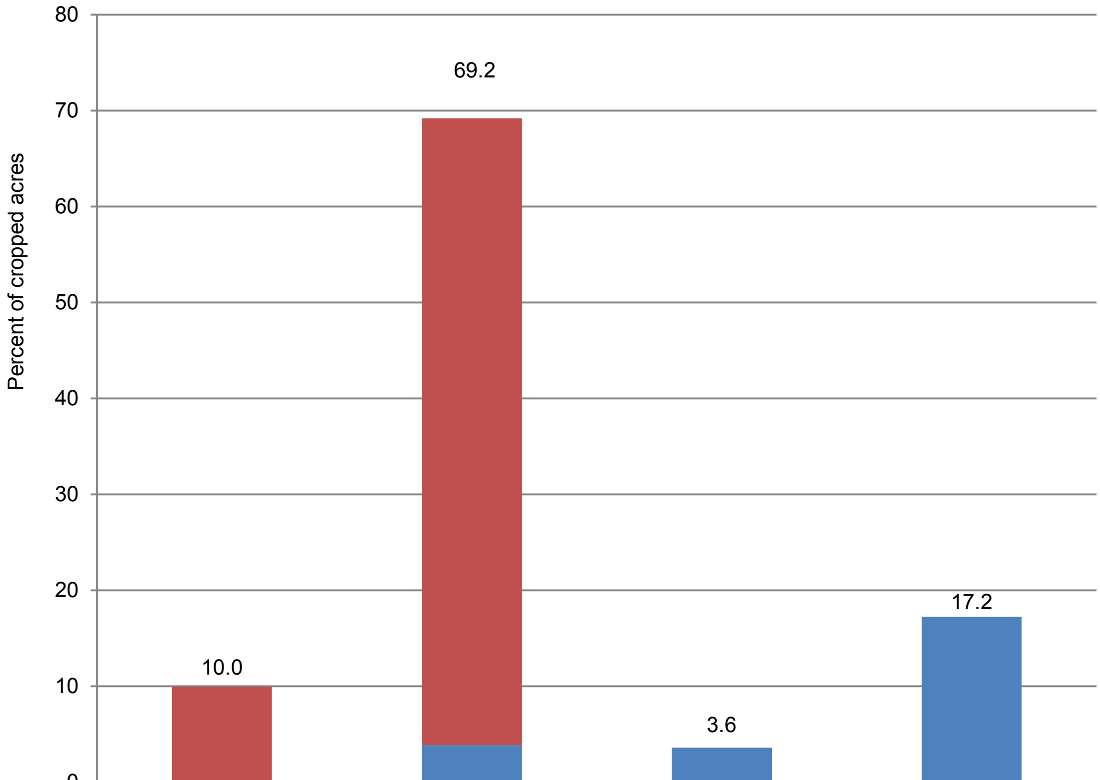
* Average annual Soil Tillage Intensity Rating (STIR) over all crop years in the rotation is less than 30.
** Average annual Soil Tillage Intensity Rating (STIR) over all crop years in the rotation is between 30 and 100.
*** Soil Tillage Intensity Rating (STIR) for every crop year in the rotation is more than 100.
Note: A description of the Soil Tillage Intensity Rating (STIR) can be found at http://stir.nrcs.usda.gov/.
Note: Percents may not add to totals because of rounding.
Note: Percent residue cover was not used to determine no-till or mulch till.
Note: HEL = highly erodible land. About 48 percent of cropped acres in the Delaware River Basin are highly erodible land (HEL).

Table 8. Percent of cropped acres with water erosion control practices for the baseline conservation condition, Delaware River Basin

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	19	5	13
No-till or mulch till with carbon loss, no structural practices	34	18	26
Some crops with reduced tillage, no structural practices	6	11	8
Structural practices and no-till or mulch till with carbon gain	9	8	8
Structural practices and no-till or mulch till with carbon loss	20	41	30
Structural practices and some crops with reduced tillage	2	3	3
Structural practices only	2	11	7
No water erosion control treatment	9	1	5
All acres	100	100	100

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

Figure 6. Percent of cropped acres at four conservation treatment levels for residue and tillage management, baseline conservation condition, Delaware River Basin



	Low	Moderate	Moderately high	High
Losing carbon	10.0	65.3	0.0	0.0
Gaining carbon	0.0	3.9	3.6	17.2

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**: Most acres in this treatment level meet criteria for no-till or mulch till but are losing soil organic carbon. Some crops have reduced tillage but tillage intensity exceeds criteria for mulch till or crop rotation is gaining soil organic carbon and tillage intensity exceeds criteria for mulch till.
- **Low treatment**: Continuous conventional tillage and crop rotation is losing soil organic carbon.

Note: Sample points that are gaining or losing soil organic carbon are identified based on APEX model output. In the annual output table, the beginning-of-year and end-of-year soil organic carbon values are recorded. The annual change in soil organic carbon is calculated as the difference between end-of-year and beginning-of-year values, which are then averaged over the 47 years of the model simulation for each sample point.

The evaluation of conservation practices are based on practice use derived from a farmer survey conducted during the years 2003–06. Use of conservation practices can vary year to year depending on economic and environmental factors, including changes in crop rotations in response to market conditions, year-to-year changes in weather-related factors affecting tillage, irrigation, and nutrient management, and conservation program funding levels and program rules.

Since the 2003–06 survey, States in the Delaware River Basin have continued to work with farmers to enhance conservation practice adoption in an ongoing effort to reduce nonpoint source pollution contributing to water quality concerns. As a result, conservation practices are likely to be in wider use within the watershed than the CEAP survey shows for 2003–06.

Cover Crops

Cover crops are planted when the principal crops are not growing. The two most important functions of cover crops from a water quality perspective 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. From a soil quality perspective, cover crops help capture atmospheric carbon in plant tissue, provide habitat for the soil food web, and stabilize or enhance soil aggregate strength.

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).
- 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 the following crop.

In the Delaware River Basin, cover crops were not commonly used as a conservation practice during the period covered by the farmer survey (2003–06). About 4 percent of the acres (7 sample points) met the above criteria for a cover crop.

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 satisfactory yields. The distribution of the rainfall during the crop growing season, however, is sometimes problematic, especially in years when precipitation is below average. In the Delaware River Basin, irrigation applications are sometimes used to supplement natural rainfall. This supplemental irrigation water can overcome soil moisture deficiencies during drought stress periods and improve yields.

Irrigation applications are made with either a pressure or a gravity system. Gravity systems, as the name implies, utilize 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 pipes and nozzles. There are also variations such as where water is diverted at higher elevations and the pressure head 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. 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 pressurized sprinkling process. Modern sprinklers utilize improved nozzle technology to increase droplet size as well as reduce the travel time from the nozzle to the ground. Irrigation specialists consider the center pivot or linear move sprinkler with low pressure spray and low flow systems such as drip and trickle systems as the current state of the art.

According to the NRI-CEAP cropland survey for 2003-06, about 13 percent of cropped acres—109,000 acres—receive irrigation water in the Delaware River Basin for one or more crops. Irrigation in the region is exclusively by pressure systems. The systems in use are mainly center pivot or linear move with either impact sprinklers or low pressure nozzles.

To evaluate the efficiency of irrigation systems, a single measure of over-all irrigation efficiency was developed—Virtual Irrigation System Efficiency (VISE). VISE consists of three variables with values unique to each of 19 types of irrigation systems. The first of the three variables is an application efficiency, which accounts for some losses from the on-farm conveyance system, the field conveyance mechanism, and as the water is applied to the field. In sprinkler systems this loss could be high due to evaporation. Application efficiency could also be reduced by leaky pipelines or ditches in more porous soils. The second factor is a coefficient that accounts for the loss of water below the root-zone, or deep percolation, during the irrigation process. The third factor accounts for the percent of water running off the edge of the field. The CEAP surveys reported few fields with runoff, even with gravity systems. While there is likely more runoff than reported, the survey values were used to define the baseline system.

Based on this analysis of the irrigation efficiencies for irrigation systems in use in the Delaware River Basin, 21 percent of irrigated cropped acres are capable of irrigation efficiencies reflecting state of the art technology, with almost all the remaining acres only requiring conversion to low pressure sprinkler heads.

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, which can contribute to 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.[8]

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 can seldom 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. For fall-planted winter wheat, spring applications also were considered appropriate timing.
- 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—
  - o less than 1.4 times the amount of nitrogen removed in the crop yield at harvest for *each* crop,[9] except for small grain crops; and
  - o 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).
- 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.

These nutrient management criteria are intended to represent practice recommendations commonly found in comprehensive nutrient management conservation plans and generally are consistent with recommended rates. While consistent with NRCS standards, they do not necessarily represent the best possible set of nutrient management practices. For example, lower application rates are possible when timing and method criteria are also met and when soil erosion and runoff are controlled.

As shown in table 9, the majority of acres in the Delaware River Basin meet one or more of the criteria for effective nitrogen management. About 4 percent of cropped acres have no nitrogen applied. An additional 62 percent of cropped acres meet criteria for timing of nitrogen applications on all crops in the rotation, 30 percent meet criteria for method of application, and 43 percent meet criteria for rate of application.

Similar results were found for phosphorus management. Less than 1 percent of cropped acres have no phosphorus applied. An additional 69 percent of cropped acres meet criteria for timing of phosphorus applications on all crops in the rotation, 52 percent meet criteria for method of application, and 48 percent meet criteria for rate of application.

[8] These criteria are also referred to as "4R nutrient stewardship—right source, right rate, right time, and right place" (Bruulsema et al. 2009).

[9] The 1.4 ratio of application rate to yield represents 70-percent use efficiency for applied nitrogen, which has traditionally been accepted as good nitrogen management practice. The 30 percent "lost" includes plant biomass left in the field, volatilization during and following application, immobilization by soil and soil microbes, and surface runoff and leaching losses. A slightly higher ratio is used for small grain crops to maintain yields at current levels.

Only a few acres meet all nutrient management criteria (table 9)—

- in addition to the 4 percent of cropped acres without nitrogen applications, 11 percent of the acres meet all criteria for nitrogen applications;
- about 26 percent of cropped acres meet all criteria for phosphorus applications; and
- only 12 percent of cropped acres meet criteria for *both* phosphorus and nitrogen management (all acres in this region had at least one phosphorus or one nitrogen application).

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 small grain crops; and
- 1.5 times the amount of nitrogen removed in the crop yield at harvest for small grain crops.

Eleven 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 (table 9).

Four levels of treatment for nitrogen and phosphorus management were derived to evaluate the adequacy of nutrient management. (These treatment levels are combined with soil risk classes to estimate acres that appear to be undertreated in chapter 5.) Criteria for the treatment levels are presented in figures 7 and 8. 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 13 percent of the acres in the Delaware River Basin have a high level of nitrogen management and about 26 percent have a high level of phosphorus management (figs. 7 and 8). About 34 percent of cropped acres have a moderately high treatment level for nitrogen and about 23 percent have a moderately high treatment level for phosphorus. About 35 percent of cropped acres have a moderate level of nitrogen management and 14 percent have a moderate level of phosphorus management. For phosphorus, however, 37 percent of cropped acres have a low level of treatment, including most of the acres with manure applied, compared to only 18 percent for nitrogen management.

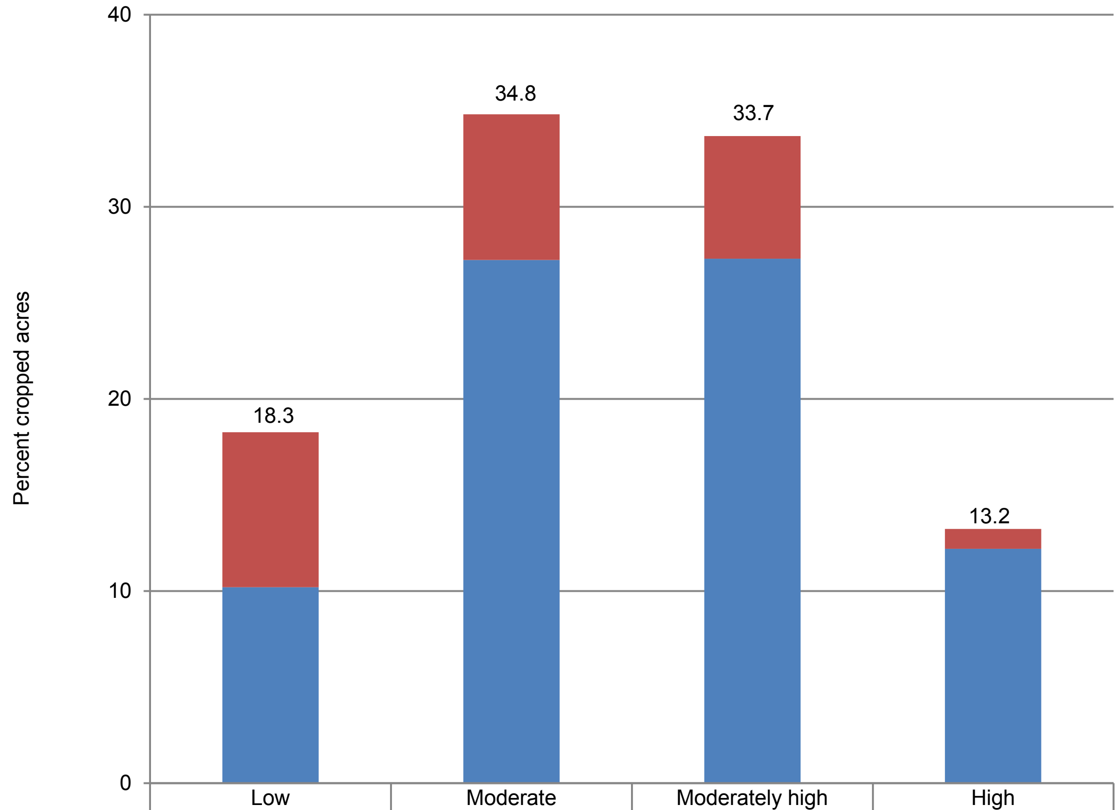
About 23 percent of cropped acres in this region had manure applied, according to the CEAP cropland survey for 2003–06. Few of these acres had a high level of nitrogen or phosphorus management. Seventy-three percent of these acres had a low level of phosphorus management, and about one-third had a low level of nitrogen management.

Table 9. Nutrient management practices for the baseline conservation condition, Delaware River Basin

	Percent of all cropped acres
Nitrogen (N)*	
No N applied to any crop in rotation	4
For samples where N is applied:	
Time of application	
All crops have application of N (manure or fertilizer) within 3 weeks before planting or within 60 after planting	62
Some but not all crops have application of N (manure or fertilizer) within 3 weeks before planting or within 60 after planting	10
No crops in rotation have application of N (manure or fertilizer) within 3 weeks before planting or within 60 days after planting	25
Method of application	
All crops in rotation have N applied with incorporation or banding/foliar/spot treatment	30
Some but not all crops in rotation have N applied with incorporation or banding/foliar/spot treatment	48
No crops in rotation have N applied with incorporation or banding/foliar/spot treatment	19
Rate of application	
All crops in rotation meet the nitrogen rate criteria described in text	43
Some but not all crops in rotation meet the nitrogen rate criteria described in text	48
No crops in rotation meet the nitrogen rate criteria described in text	5
Timing and method and rate of application	
All crops meet the nitrogen rate criteria, timing criteria, and method criteria described above	11
Some but not all crops meet the nitrogen rate criteria, timing criteria, and method criteria described above	55
No crops meet the nitrogen rate , timing criteria, and method criteria described above	30
Phosphorus (P)*	
No P applied to any crop in rotation	<1
For samples where P is applied:	
Time of application	
All crops in rotation have application of P (manure or fertilizer) within 3 weeks before planting or within 60 days after planting	69
Some but not all crops have application of P (manure or fertilizer) within 3 weeks before planting or within 60 days after planting	8
No crops in rotation have application of P (manure or fertilizer) within 3 weeks before planting or within 60 days after planting	23
Method of application	
All crops in rotation have P applied with incorporation or banding/foliar/spot treatment	52
Some but not all crops in rotation have P applied with incorporation or banding/foliar/spot treatment	37
No crops in rotation have P applied with incorporation or banding/foliar/spot treatment	10
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
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	51
Timing and method and rate of application	
Crop rotation has P rate less than 1.1 times removal at harvest and meet timing and method criteria described above	26
Crop rotation has P rate less than 1.1 times removal at harvest and some but not all crops meet timing and method criteria described above	20
Crop rotation has P rate more than 1.1 times removal at harvest and may or may not meet timing and method criteria described above	54
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 within 60 days after planting with incorporation or banding/foliar/spot treatment, including acres with no N or P applied	12
Crop rotation P rate less than 1.1 and N rate criteria appropriate for full conservation treatment (see text) and all applications within 3 weeks before planting or within 60 days after planting with incorporation or banding/foliar/spot treatment, including acres with no N or P applied	11
All sample points	100

* 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 41 percent of the acres received a nitrogen adjustment for one or more crops. About 32 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 the documentation report "Adjustment of CEAP Cropland Survey Nutrient Application Rates for APEX Modeling," as referenced on page 5).

Figure 7. Percent of cropped acres at four conservation treatment levels for nitrogen management, baseline conservation condition, Delaware River Basin

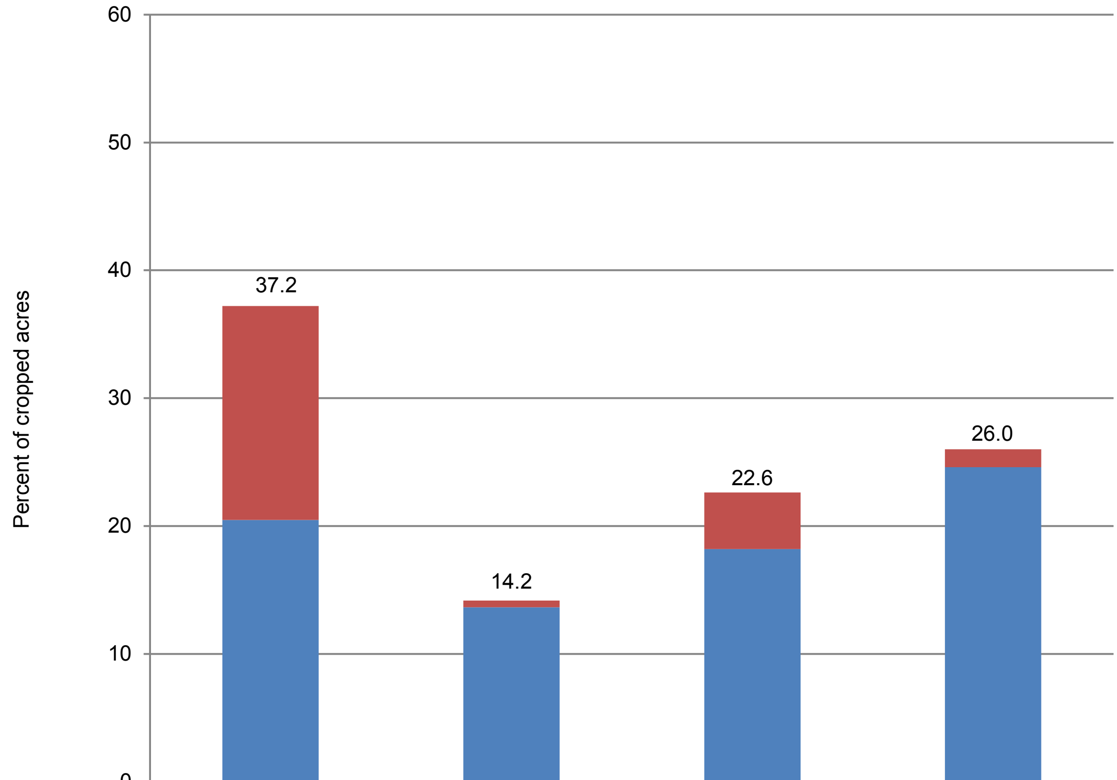


	Low	Moderate	Moderately high	High
Manure applied	8.1	7.6	6.4	1.0
No manure applied	10.2	27.2	27.3	12.2

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 small grain crops and less than 1.5 times the nitrogen in the crop yield for small grains; (2) all applications occur within 3 weeks before planting or within 60 days 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 small grain crops and less than 1.6 times the nitrogen in the crop yield for small grains. 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 8. Percent of cropped acres at four conservation treatment levels for phosphorus management, baseline conservation condition, Delaware River Basin



	Low	Moderate	Moderately high	High
Manure applied	16.7	0.5	4.4	1.4
No manure applied	20.5	13.6	18.2	24.6

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 within 60 days 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 method 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).[10]

Adoption of IPM systems can be described as occurring along a continuum from largely reliant on prophylactic control measures and pesticides to multiple-strategy, biologically intensive approaches. IPM adoption 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, 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.

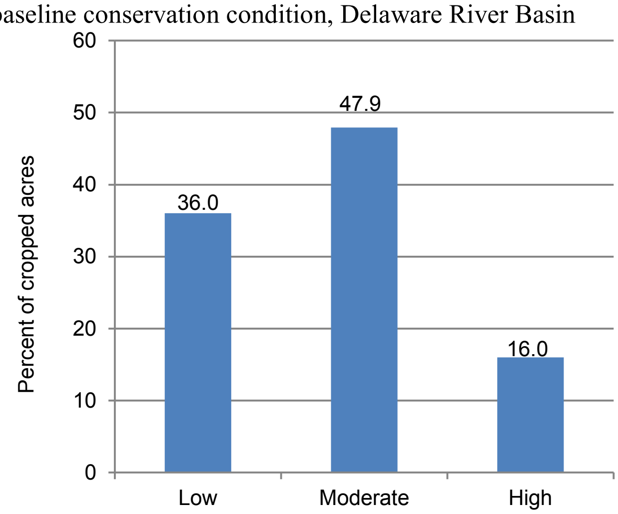
An IPM index was developed to determine the level of IPM activity for each sample point. The index was constructed as follows.

- Scores were assigned to each IPM-related survey question by a group of IPM experts.
- Scores for each PAMS category were normalized to have a maximum score of 100 across the set of sample points in the region.
- 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 16 percent of the acres in the Delaware River Basin have a high level of IPM activity (fig. 9). About 48 percent have a moderate level of IPM activity, and 36 percent have a low level of IPM activity.

Figure 9. Integrated Pest Management indicator for the baseline conservation condition, Delaware River Basin



[10] For a full documentation of the derivation of the IPM indicator, see the documentation report "Integrated Pest Management (IPM) Indicator Used in the CEAP Cropland Modeling;" referenced on page 5.

Table 10. Summary of survey responses to pest management questions, Delaware River Basin

Survey question	Number samples with "yes" response	Percent of cropped acres
Prevention		
Pesticides with different action rotated or tank mixed to prevent resistance	74	41%
Plow down crop residues	63	33%
Chop, spray, mow, plow, burn field edges, etc.	85	46%
Clean field implements after use	75	36%
Remove crop residue from field	32	19%
Water management used to manage pests (irrigated samples only)	8	4%
Avoidance		
Rotate crops to manage pests	141	78%
Use minimum till or no-till to manage pests	119	68%
Choose crop variety that is resistant to pests	75	41%
Planting locations selected to avoid pests	31	14%
Plant/harvest dates adjusted to manage pests	16	7%
Monitoring		
Scouting practice: general observations while performing routine tasks	66	38%
Scouting practice: deliberate scouting	100	49%
--Established scouting practice used	53	20%
--Scouting due to pest development model	20	11%
--Scouting due to pest advisory warning	29	14%
Scouting done by: (only highest of the 4 scores is used)		
--Scouting by operator	59	31%
--Scouting by employee	2	1%
--Scouting by chemical dealer	18	6%
--Scouting by crop consultant or commercial scout	24	11%
Scouting records kept to track pests?	57	25%
Scouting data compared to published thresholds?	58	25%
Diagnostic lab identified pest?	25	12%
Weather a factor in timing of pest management practice	66	39%
Suppression		
Pesticides used?	178	96%
Weather data used to guide pesticide application	113	65%
Biological pesticides or products applied to manage pests	21	8%
Pesticides with different mode of action rotated or tank mixed to prevent resistance	74	41%
Pesticide application decision factor (one choice only):		
--Routine treatments or preventative scheduling	90	52%
--Comparison of scouting data to published thresholds	12	4%
--Comparison of scouting data to operator's thresholds	17	8%
--Field mapping or GPS	0	0%
--Dealer recommendations	19	10%
--Crop consultant recommendations	14	6%
--University extension recommendations	3	2%
--Neighbor recommendations	1	<1%
--"Other"	9	5%
Maintain ground covers, mulch, or other physical barriers	101	58%
Adjust spacing, plant density, or row directions	40	19%
Release beneficial organisms	4	1%
Cultivate for weed control during the growing season	34	17%
Number of respondents	186	100%

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

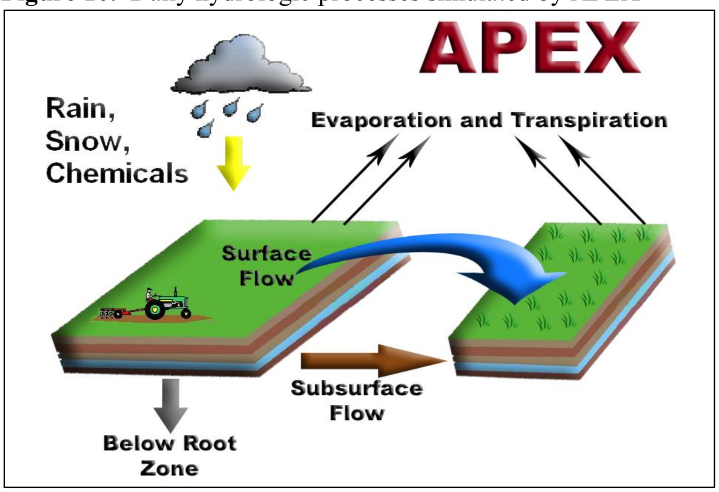
Chapter 4
Onsite (Field-Level) Effects of Conservation Practices

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).[11] 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.[12]

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. 10). 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).[13]

Figure 10. 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, depending on climatic conditions, cropping systems, and management.

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.[14]

Use of conservation practices in the Delaware River Basin 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.[15]

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

[12] The IAPEX 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.

[13] 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 in the collection of CEAP documentation reports referenced on page 5.

[14] For a detailed description of the rules and procedures, see the documentation report "Transforming Survey Data to APEX Model Input Files," referenced on page 5.

[15] For a detailed description of the rules and procedures for simulation of structural conservation practices, see the documentation report "Modeling Structural Conservation Practices in APEX," referenced on page 5.

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 Delaware River Basin 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 inadequate conservation so that a reasonable 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 Delaware River Basin

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	1. USLE P-factor changed to 1 and slope length increased for points with terraces, soil condition changed from good to poor.
	2. Concentrated flow—managed structures or waterways present	2. Structures and waterways replaced with earthen ditch, soil condition changed from good to poor.
	3. Edge-of-field mitigation practices present	3. Removed practice and width added back to field slope length.
	4. Wind erosion control practices present	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 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)
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 any increase in manure applications to meet nitrogen application criteria for the no practice scenario. Manure applications were not further 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	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. Practicing moderate level of IPM	2. Same as for high level of IPM, except replication of first application only 1 time, 1 week after original
	3. Spot treatments	3. Application rates for spot treatments were adjusted upward relative to the baseline rate to represent whole-field application (see text)
	4. Partial field treatments	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 overall 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.

For the no-practice scenario, the center pivots/linear move sprinkler systems were converted to hand move lines. In addition, all conservation practices, such as Irrigation Water Management and Irrigation Land Leveling, were removed.

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 nutrients to meet realistic yield goals. The standard addresses nutrient loss in two primary ways: (1) by altering rates, form, timing, and methods of application, and (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.

Commercial nitrogen fertilizer 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 1.4 times the amount of nitrogen removed at harvest in the baseline scenario, except for small grain crops; and
- increased to 2.0 times harvest removal for small grain crops receiving less than or equal to 1.6 times the amount of nitrogen removed at harvest 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.

The assessment 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.

Commercial phosphorus fertilizer rate. The threshold for identifying proper phosphorus application rates was 1.1 times the amount of phosphorus taken up by all the crops in the rotation and removed at harvest. The threshold is lower for phosphorus than for nitrogen 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 the crop rotation. 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.

Manure application rate. For sites receiving manure, the appropriate manure application rate in tons per acre was identified on the basis of the total nitrogen application rate, including both manure and commercial nitrogen fertilizer. Thus, if the total for all applications of nitrogen (commercial fertilizer and manure) was less than or equal to 1.4 times removal at harvest for non-legume crops, the no-practice manure application rate was increased such that the combination of commercial fertilizer and manure applications resulted in a total rate of nitrogen application equal to 1.98 times harvest removal. Both commercial nitrogen fertilizer and the amount of manure were increased proportionately to reach the no-practice scenario rate. For small grains, the same approach was used using the criteria defined above for commercial nitrogen fertilizer. As done with commercial nitrogen fertilizer, the assessment was made separately for each crop in the rotation.

Any increase in phosphorus from manure added to meet the nitrogen criteria for the no-practice scenario was taken into account in setting the no-practice commercial phosphorus fertilizer application rate.

Thus, no adjustment was made to manure applied at rates below the P threshold of 1.1 in the no-practice scenario because the manure application rate was based on the nitrogen level in the manure.

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 for the no-practice scenario.

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 for the no-practice scenario.

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.[16] 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—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 pesticide application rate as originally reported was used, simulating treatment of the entire field rather than 5 percent of the field. In the Delaware River Basin, sample points with spot treatments represented less than 1 percent of the cropped acres**.**

Partial field treatments were simulated in a manner similar to spot treatments. Partial field treatments were determined using information reported in the survey on the percentage of the field that was treated. (Spot treatments, which are also partial field treatments, were treated separately as described above.) 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 on less than one-third of the field, as larger partial field treatments could have been for reasons unrelated to IPM. Less than 1 percent of the cropped acres in the Delaware River Basin had partial field treatments of pesticides.

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, 1 week and 2 weeks after its original application. For moderate IPM cases, the first application event was replicated one time for each crop, 1 week after its original application.

[16] 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.

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 Delaware River Basin 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 for cropped acres over the 47-year simulation averaged about 45 inches in this region (fig. 4). About 13 percent of the cropped acres are irrigated, at an average application of 12.7 inches per year (table 12).

Most of the water that leaves the field is lost through evaporation and transpiration (evapotranspiration) (fig. 11). Evapotranspiration is the dominant loss pathway for all cropped acres in this region. On average, about 28 inches per year are lost through evapotranspiration, representing about 60 percent of total water loss (table 12). Model results indicate that evapotranspiration losses vary, however, according to soil characteristics and land cover; evapotranspiration ranges from about 50 percent to about 70 percent of the total amount of water that leaves the field on most acres in this region (fig. 12).

The remaining water is lost in surface water runoff (15 percent of total water loss, on average) and in subsurface flow pathways (25 percent of total water loss, on average). Subsurface flow pathways include—

1. deep percolation to groundwater, including groundwater return flow to surface water,
2. subsurface flow that is intercepted by tile drains or drainage ditches, when present, and
3. lateral subsurface outflow or quick-return flow that emerges as surface water runoff, such as natural seeps.

Loss of water to subsurface flows is higher than losses to surface water on most cropped acres (figs. 11 and 12). On average, about 12 inches per year are lost to subsurface flow pathways, while only 7 inches per year are lost as surface water runoff (table 12).

Figure 11. Estimates of average annual water lost through three loss pathways for cropped acres in the Delaware River Basin

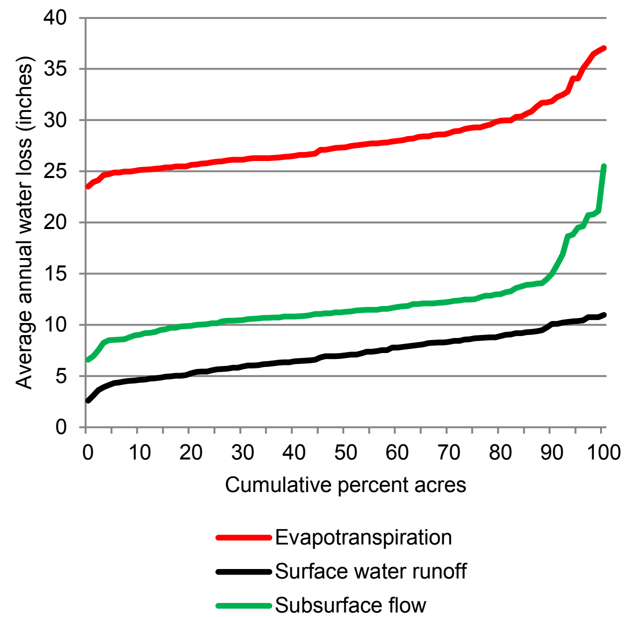
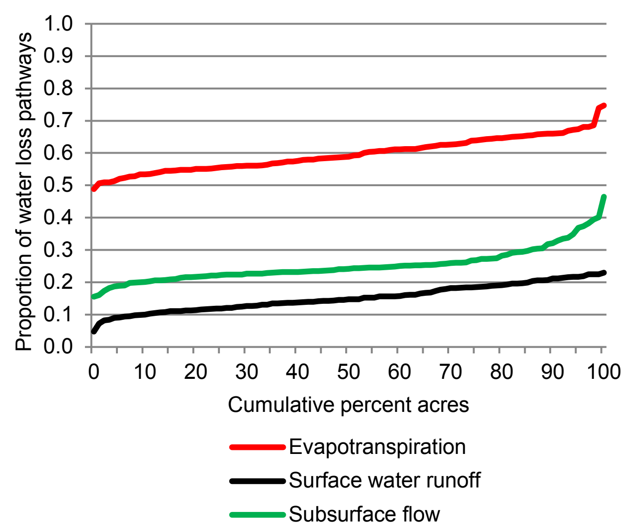


Figure 12. Cumulative distributions of the proportion of water lost through three loss pathways for cropped acres, Delaware River Basin



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.

Tile Drainage

Tile drainage flow is included in the water loss category "subsurface water flows" in this report. (See table 12.) Other components of subsurface water flow include: 1) deep percolation to groundwater, including groundwater return flow to surface water, 2) lateral subsurface flows intercepted by surface drainage ditches, and 3) lateral subsurface outflow or quick-return flow that emerges as surface water runoff, such as natural seeps. While the farmer survey provided information on whether or not the field with the CEAP sample point had tile drainage, tile drainage flow and loss of soluble nutrients in tile drainage water are not reported separately because other important information on the tile drainage characteristics were not covered in the survey. The missing information includes: depth and spacing of the tile drainage field; extent of the tile drainage network; proportion of the field, or other fields, that benefited from the tile drainage system; and extent to which overland flow and subsurface flow from surrounding areas enters through tile surface inlets. In the Delaware River Basin, about 12 percent of the cropped acres have some portion of the field that is tile drained, according to the farmer survey.

Table 12. Field-level effects of conservation practices on water loss pathways for cropped acres (845,600 acres) in the Delaware River Basin

Model simulated outcome	Baseline conservation condition	No-practice scenario	Reduction due to practices	Percent reduction
Water sources				
Non-irrigated acres				
Average annual precipitation (inches)	45.2	45.2	0.0	0
Irrigated acres				
Average annual precipitation (inches)	43.7	43.7	0.0	0
Average annual irrigation water applied (inches)*	12.7	25.1	12.5	50
Water loss pathways				
Average annual evapotranspiration (inches)	28.0	28.2	0.2	1
Average annual surface water runoff (inches)	7.1	8.0	0.9	11
Average annual subsurface water flows (inches)**	11.9	11.3	-0.6***	-5%***

* About 13 percent of the cropped acres in the Delaware River Basin are irrigated.

** 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 0.6 inches per year (5-percent increase) for cropped acres due to the use of conservation practices.

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

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 186 sample points used to represent cropped acres in the Delaware River Basin. 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 13, 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 186 surface water runoff estimates, weighted by the acres associated with each sample point. The 10th percentile for the baseline conservation condition is 4.6 inches per year, indicating that 10 percent of the acres have 4.6 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 5.6 inches per year. The 50th percentile—the median—is 6.9 inches per year, which in this case is somewhat less than the mean value of 7.1 inches per year. At the high end of the distribution, 90 percent of the acres in this region have surface water runoff less than 10.1 inches per year; and conversely, 10 percent of the acres have surface water runoff greater than 10.1 inches per year.

Thus, the distributions show the full range of outcomes for cultivated cropland acres in the Delaware River Basin. The full range of outcomes for the baseline condition is compared to that for the no-practice scenario in figure 13 to illustrate the extent to which conservation practices reduce surface water runoff throughout the region.

Figure 14 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 186 cropped sample points. This distribution shows that, while the median reduction is 0.7 inch per year, 10 percent of the acres have reductions due to conservation practices greater than 2 inches per year and 13 percent of the acres actually have small increases in surface water runoff (i.e., negative reductions) as a result of conservation practice use.

Effects of conservation practices on cropped acres

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.[17] Model simulations indicate that conservation practices have reduced surface water runoff by about 1 inch per year averaged over all cropped acres, representing an 11-percent reduction on average (table 12).

The re-routing of surface water to subsurface flows is shown graphically in figures 13 and 14 for cropped acres. The no-practice scenario curve in figure 13 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 and less soil moisture available for crop growth.

Reductions in surface water runoff due to conservation practices range from less than zero to more than 4 inches per year (fig. 14).[18] 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.

The re-routing of surface water to subsurface flows results in an average gain in this region of about 0.6 inch per year in subsurface flows due to the use of conservation practices (table 12), representing a 5-percent increase.

Use of improved irrigation systems in the Delaware River Basin increases overall system efficiency from 39 percent in the no-practice scenario to 67 percent in the baseline scenario. This change in efficiency represents an annual decreased need of water diversions of about 12.5 inches per year where irrigation is used (table 12).

Figure 13. Estimates of average annual surface water runoff for cropped acres in the Delaware River Basin

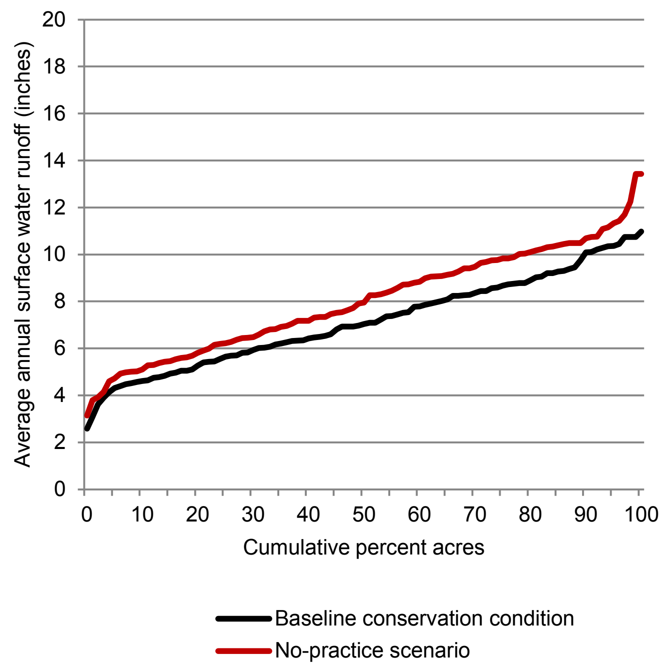
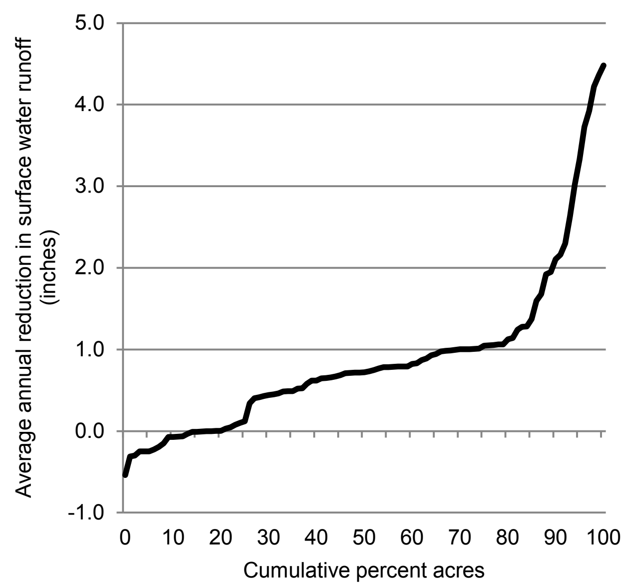


Figure 14. Estimates of average annual reduction in surface water runoff due to the use of conservation practices on cropped acres in the Delaware River Basin



[17] Model simulations did not include increased infiltration for some structural practices—model parameter settings conservatively prevented infiltration of run-on water and its dissolved contaminants in conservation buffers including field borders, filter strips and riparian forest buffers.

[18] About 13 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.

Effects of Practices on Wind Erosion

Wind velocity, tillage, vegetative cover, and the texture and structure of the soil are primary determinants of 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 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.

A concern of crop producers with wind erosion is crop damage to young seedlings exposed to windblown material. Wind erosion rates as low as 0.5 ton per acre have been known to cause physical damage to young seedlings.

Wind erosion can also deposit sediment rich in nutrients into adjacent ditches and surface drainage systems, where it is then transported to water bodies with runoff. Wind erosion rates greater than 2 tons per acre per year can result in significant losses of soil and associated contaminants over time. Wind erosion rates greater than 4 tons per acre can result in excessive soil loss annually and can also have adverse effects on human health.

Baseline condition for cropped acres

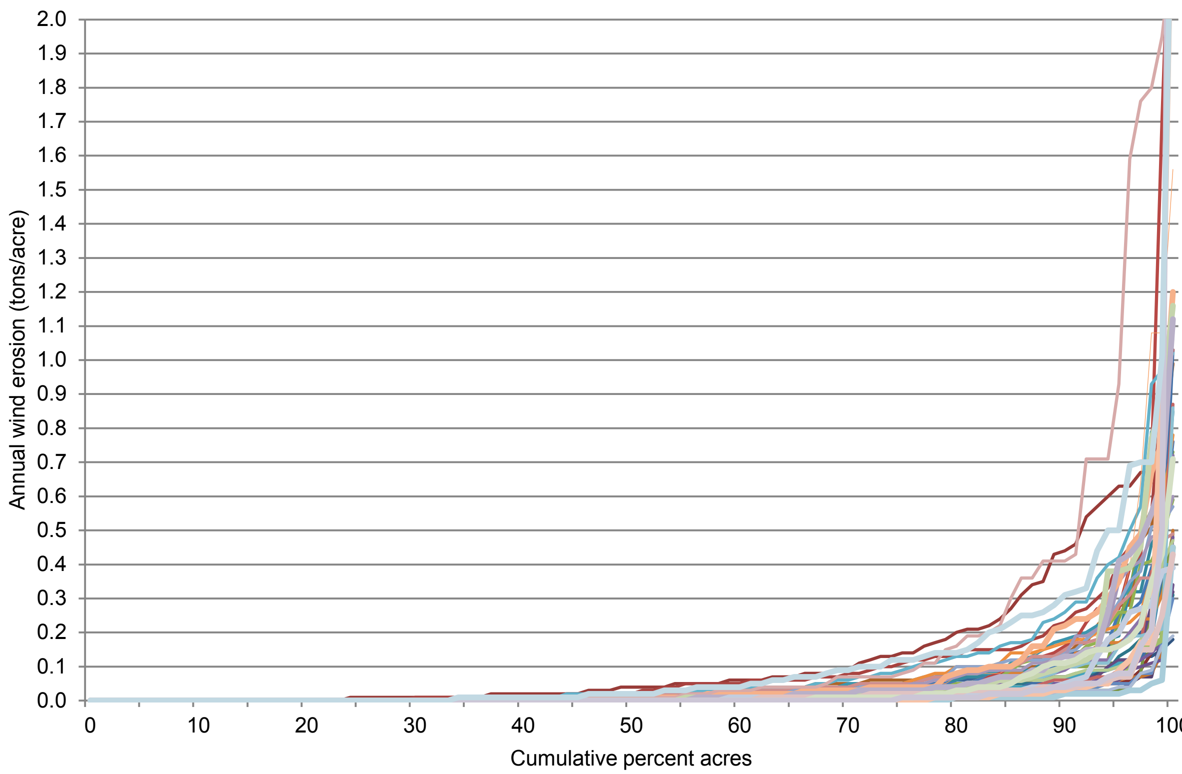
Wind erosion is a relatively minor resource concern in the Delaware River Basin. For all cropped acres, model simulations show that the average annual rate of wind erosion is only 0.04 ton per acre (table 13). However, annual wind erosion can exceed 0.5 ton per acre on some acres in the region in most years and even exceed 1 ton per acre on some acres in some years (fig. 15). In the most extreme year included in the model simulations (representing 1997), wind erosion exceeded 0.5 ton per acre for 8 percent of the cropped acres.

Table 13. Average annual wind erosion modeling results for cropped acres (845,600 acres) in the Delaware River Basin

Baseline conservation condition (tons/acre)	0.04
No-practice scenario (tons/acre)	0.07
Reduction due to practices (tons/acre)	0.03
Percent reduction	39%

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

Figure 15. Distribution of annual wind erosion rate for each year of the 47-year model simulation, Delaware River Basin



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 conservation practices

Farmers address wind erosion using conservation practices designed to enhance the soil's ability to resist and reduce the wind velocity near the soil surface. Properly planned and applied residue management reduces wind erosion by leaving more organic material on the soil surface, which in turn helps preserve soil aggregate stability and promotes further aggregation. Physical barriers such as windbreaks or shelterbelts, herbaceous wind barriers or windbreaks, cross wind trap strips, or ridges constructed perpendicular to the prevailing wind direction also reduce the intensity of wind energy at the surface. Row direction or arrangement, surface roughening, and stripcropping also lessen the wind's energy.

Structural practices for wind erosion control are in use on only 7 percent of the cropped acres in the Delaware River Basin. 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 39 percent in the region (table 13). Reductions in wind erosion due to conservation practices are higher for some acres than others, reflecting both the level of treatment and the inherent erodibility of the soil (figs. 16 and 17). For 85 percent of cropped acres, reductions due to conservation practices are less than 0.05 ton per acre per year, on average. For some acres (8 percent), wind erosion rates increased slightly with conservation practice use (fig. 17). This condition can occur because of the higher fertilization rates used to simulate the no-practice scenario, which can result in more vegetative cover protecting the soil from the forces of the wind.

Figure 16. Estimates of average annual wind erosion for cropped acres in the Delaware River Basin

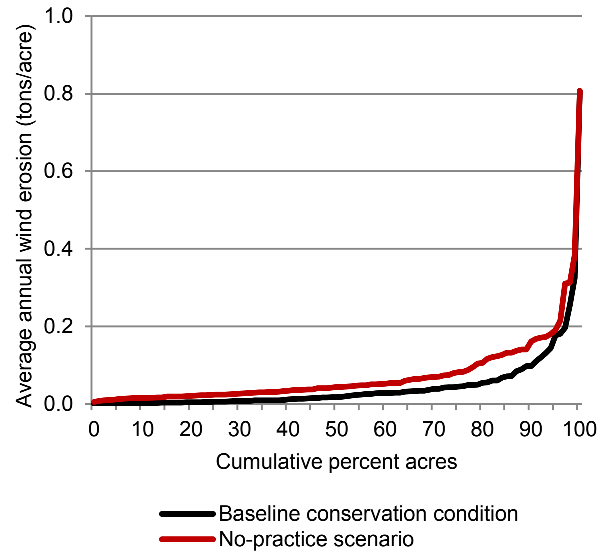
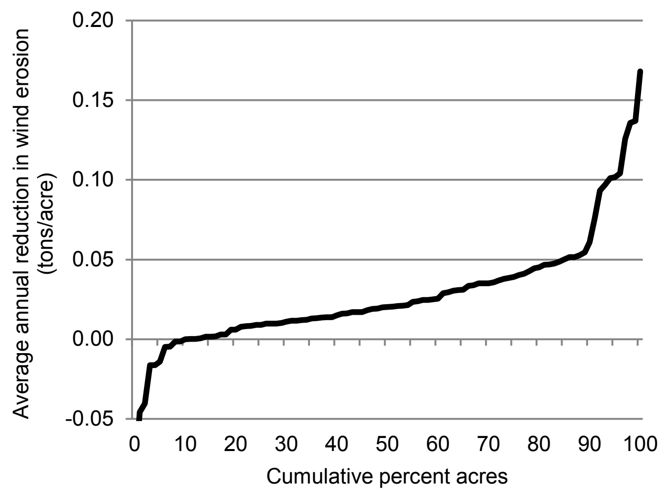


Figure 17. Estimates of average annual reduction in wind erosion due to the use of conservation practices on cropped acres in the Delaware River Basin



Effects of Practices on Water Erosion and Sediment Loss

Forms of water erosion include sheet and rill, ephemeral gully, classical gully, and streambank. Each type is associated with the progressive concentration of runoff water into channels leading downslope.

Sheet and rill erosion

The first stage of water erosion is sheet and rill erosion, which can be modeled using the Universal Soil Loss Equation (USLE). 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 and nutrients from leaving the field.

Model simulations show that sheet and rill erosion on cropped acres in the Delaware River Basin averages about 1.7 tons per acre per year (table 14). Sheet and rill erosion rates for highly erodible land average 2.8 tons per acre per year compared to the average annual rate for non-highly erodible land of 0.7 ton per acre.

Model simulation results also show that conservation practices have reduced sheet and rill erosion on cropped acres in the Delaware River Basin by an average of 0.8 ton per acre per year, representing a 33-percent reduction on average (table 14). The average annual reduction in sheet and rill erosion for highly erodible land is more than four times that for non-highly erodible acres (table 14).

Sediment loss from water erosion

Soil erosion and sedimentation are separate but interrelated resource concerns. 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 is transported beyond the edge of the field and settles offsite as well as some sediment that originates from gully erosion processes. Sediment is composed of detached and transported soil minerals, organic matter, plant and animal residues, and associated chemical and biological compounds. Edge-of-field conservation practices are designed to filter out a portion of the material and reduce sediment loss.

For this study, the APEX model was set up to estimate sediment loss using a modified version of MUSLE, called MUST (not MUSS, as was mistakenly reported in the CEAP reports on the Chesapeake Bay, the Great Lakes, and the Ohio-Tennessee River Basins).[19] The model variant called MUST 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.

Baseline condition for cropped acres. The average annual sediment loss from water erosion for cropped acres in the Delaware River Basin is 2.5 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.

On an annual basis, sediment loss varies from year to year, although high losses are restricted to a minority of acres each year. Figure 18 shows that, with the conservation practices currently in use in the Delaware River Basin, annual sediment loss is below 2 tons per acre in all years for about 45 percent of the acres, including years with high precipitation. In contrast, sediment loss exceeds 4 tons per acre in one or more years on about 40 percent of the cropped acres in the region. The highest losses shown in figure 18 are for acres that have the highest inherent vulnerability to water erosion and have inadequate soil erosion control.

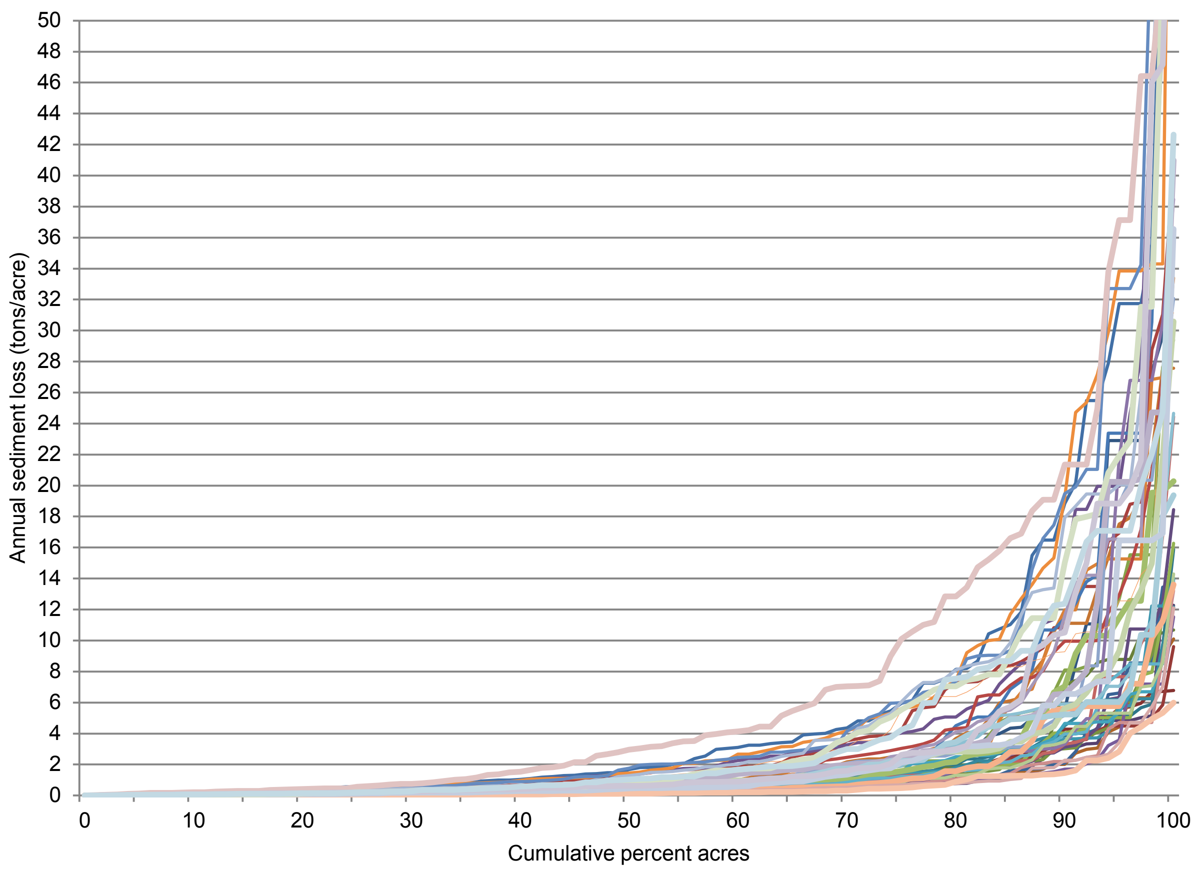
[19] APEX provides a variety of options for modeling erosion and sedimentation, including USLE, RUSLE, MUSS, MUSLE, and MUST. MUST is the most appropriate choice for simulation of sediment loss for small areas (less than 1 hectare, for example).

Table 14. Field-level effects of conservation practices on erosion and sediment loss for cropped acres (845,600 acres) in the Delaware River Basin

Model simulated outcome	Baseline conservation condition	No-practice scenario	Reduction due to practices	Percent reduction
All cropped acres				
Average annual sheet and rill erosion (tons/acre)*	1.70	2.54	0.84	33
Average annual sediment loss at edge of field due to water erosion (tons/acre)**	2.49	4.43	1.93	44
Highly erodible land (48 percent of cropped acres)				
Average annual sheet and rill erosion (tons/acre)*	2.80	4.20	1.40	33
Average annual sediment loss at edge of field due to water erosion (tons/acre)**	4.33	7.67	3.34	43
Non-highly erodible land (52 percent of cropped acres)				
Average annual sheet and rill erosion (tons/acre)*	0.68	1.01	0.33	32
Average annual sediment loss at edge of field due to water erosion (tons/acre)**	0.81	1.45	0.64	44

* Estimated using the Revised Universal Soil Loss Equation.
**Estimated using MUST, which includes some sediment from gully erosion. See text.
Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text.

Figure 18. Distribution of annual sediment loss for each year of the 47-year model simulation, Delaware River Basin



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.

Effects of conservation practices on cropped acres. Model simulations indicate that the use of conservation practices in the Delaware River Basin has reduced average annual sediment loss from water erosion by 44 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 4.4 tons per acre per year compared to 2.5 tons per acre average for the baseline conservation condition.

The effects of conservation practices on reducing sediment loss in this region are small for most acres but much larger for other acres, as shown in figures 19 and 20. Figure 19 shows that about 51 percent of the acres would have more than 2 tons per acre per year sediment loss without practices, on average, compared to 31 percent with conservation practices. Conservation practices have reduced the average annual sediment loss by 1 ton per acre or more on 48 percent of the cropped acres, as shown in figure 20.

The highest percent reductions were generally for acres with structural practices and/or acres meeting criteria for no-till or mulch-till with annual increases in soil organic carbon (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 8 percent of cropped acres), have reduced sediment loss by 87 percent, on average. For these treated acres, annual sediment loss averages only about 0.2 ton per acre.

Figure 19. Estimates of average annual sediment loss for cropped acres in the Delaware River Basin

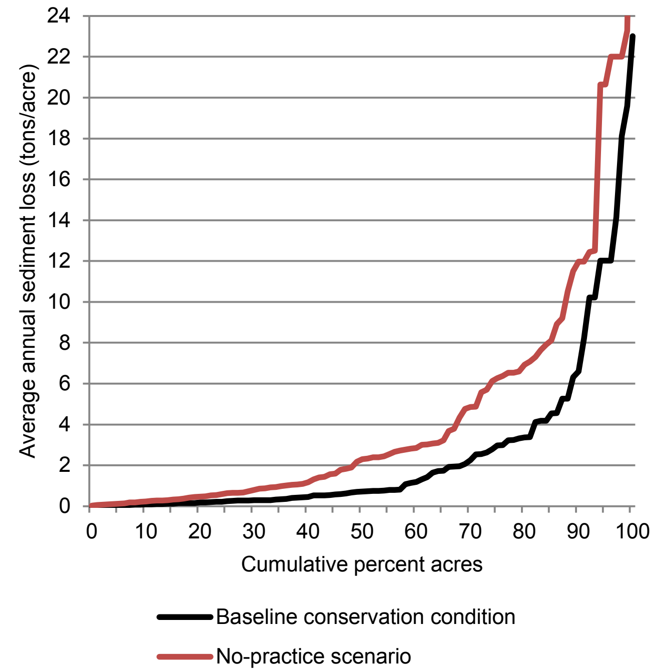


Figure 20. Estimates of average annual reduction in sediment loss due to the use of conservation practices on cropped acres in the Delaware River Basin

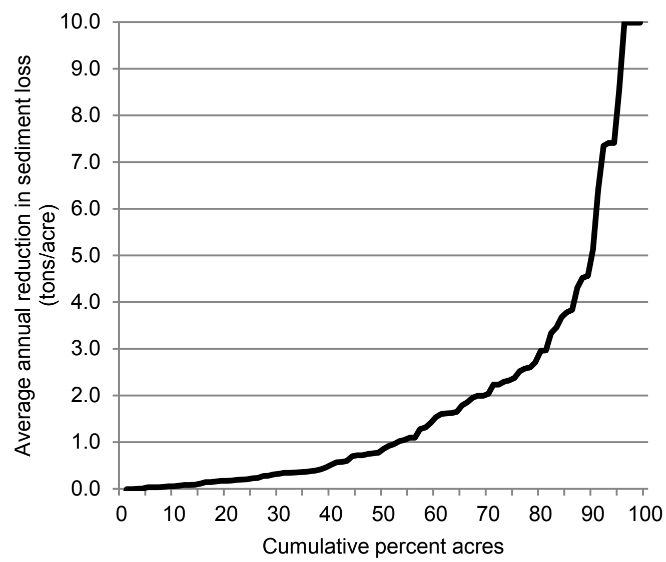


Table 15. Estimates of effects of combinations of structural practices and residue and tillage management on average annual sediment loss for cropped acres in the Delaware River Basin

Conservation treatment	Percent of cropped acres	Average annual sediment loss (tons/acre): Baseline conservation condition	No-practice scenario	Reduction due to practices	Percent reduction
No-till or mulch till with carbon gain, no structural practices	13	0.47	1.07	0.60	56
No-till or mulch till with carbon loss, no structural practices	26	1.65	2.66	1.01	38
Some crops with reduced tillage, no structural practices	8	4.34	5.64	1.30	23
Structural practices and no-till or mulch till with carbon gain	8	0.21	1.61	1.40	87
Structural practices and no-till or mulch till with carbon loss	30	4.32	8.14	3.83	47
Structural practices and some crops with reduced tillage	3	0.46	1.35	0.89	66
Structural practices only	7	2.86	5.57	2.71	49
No water erosion control treatment	5	2.21	2.45	0.24	10*
All acres	100	2.49	4.43	1.93	44

* These acres have a small reduction in sediment loss even though they have no water erosion control treatment. For non-irrrigated sample points, the reduction due to practices for these acres 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.

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 Practices on Soil Organic Carbon

The landscape and climate in the Delaware River Basin 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 more challenging. The soils in this region developed from residuum of 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 such as the Mississippi River drainage basin.

The soils and the cropping systems are similar to those in the adjoining Chesapeake Bay Basin to the south. However, the percentage of acres gaining soil organic carbon is lower in the Delaware River Basin, 25 percent of cropped acres as compared to 43 percent for the Chesapeake Bay Region. This difference is largely driven by a lower proportion of no-till acres in the Delaware River Basin (32 percent) as compared to the Chesapeake Bay Region (48 percent). While the slightly cooler climate in the Delaware River Basin would tend to be more conducive to storing carbon, the slightly shorter growing season for crops would tend to reduce biomass production; however, these climatic differences are negligible as compared to the tillage effects.

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 103 pounds per acre per year, on average (table 16). About 25 percent of cropped acres are gaining soil organic carbon (fig. 21) at an average rate of 77 pounds per acre per year. In contrast, 75 percent of cropped acres are losing soil organic carbon at an average rate of 162 pounds per acre per year.

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 212 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 through enhanced soil aggregate stability.

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 (fig. 21). When combined with acres enhancing soil organic carbon, a total of 58 percent of the acres in the region would be either maintaining or enhancing soil organic carbon.

Table 16. Field-level effects of conservation practices on soil organic carbon for cropped acres (845,600 acres) in the Delaware River Basin

Model simulated outcome	Baseline conservation condition	No-practice scenario	Reduction due to practices	Percent reduction
Average annual loss of carbon with wind and water erosion (pounds/acre)	212	239	27	11
Average annual change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)*	-103	-141	37**	--

* Average soil organic carbon values for each sample point were obtained from APEX model output. In the annual output table, the beginning-of-year and end-of-year soil organic carbon values are recorded. The annual change in soil organic carbon is calculated as the difference between end-of-year and beginning-of-year values, which are then averaged over the 47 years of the model simulation for each sample point. Values in the table were obtained by calculating the weighted average over the sample points in the region.

** 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.

Effects of conservation practices on cropped acres

In this region, conservation practices have a relatively modest effect on soil organic carbon levels for most acres, as shown in figures 21 and 22. Without conservation practices, the annual change in soil organic carbon would be an average loss of 141 pounds per acre per year, compared to an average loss of 103 pounds per acre for the baseline (table 16). Thus, conservation practice use in the region has resulted in an average annual gain in soil organic carbon of 37 pounds per acre per year on cropped acres.

The average annual gain in soil organic carbon due to practices varies among acres, however, depending on the extent to which residue and nutrient management is used, as well as the soil's potential to sequester carbon. Only about 12 percent of cropped acres in this region gain more than 100 pounds per acre of soil organic carbon due to conservation practice use (figure 22).

Figure 22 also shows that about 15 percent of the acres have a reduction in soil organic carbon due to conservation practice use. (A reduction is represented as a negative gain in figure 22.) This occurs because of the higher fertilization rates used in the no-practice scenario, including manure application rates, to simulate the effects of nutrient management practices.

Conservation practice use appears to have little or no effect on the loss of soil organic carbon due to wind and water erosion in this region (table 16). The loss of carbon with wind and water erosion averaged 212 pounds per acre per year for the baseline, and slightly more at 239 pounds per acre for the no-practice scenario. Thus, on average for the region, conservation practice use results in a reduction of 27 pounds per acre per year in the loss of carbon with wind and water erosion, representing an 11-percent annual reduction on average.

For air quality concerns, the analysis centers on the decrease in carbon dioxide 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 gain in soil organic carbon of 37 pounds per acre due to conservation practice use is equivalent to an emission reduction of 58,000 U.S. ton of carbon dioxide for the Delaware River Basin.

Figure 21. Estimates of average annual change in soil organic carbon for cropped acres in the Delaware River Basin

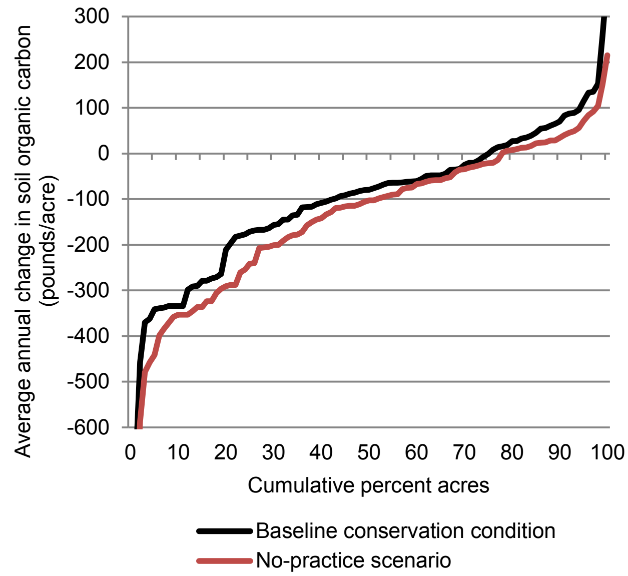
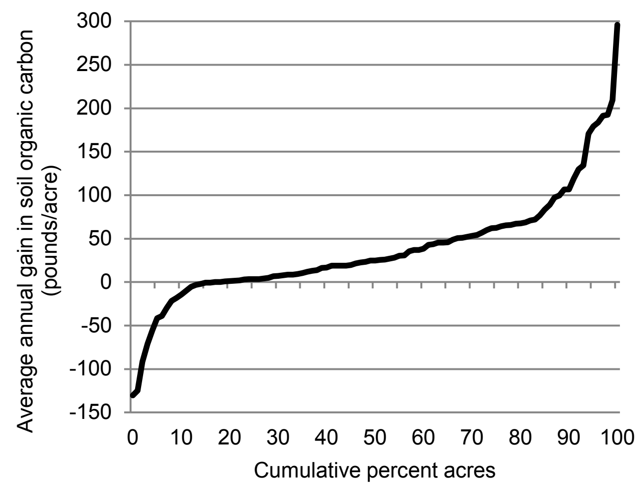


Figure 22. Estimates of average annual gain in soil organic carbon due to the use of conservation practices on cropped acres in the Delaware River Basin



Note: See text for explanation of negative gains due to conservation practice use.

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, dry beans, and peas), a small amount of manure deposited by grazing livestock, and atmospheric nitrogen deposition. On average, these sources provide about 120 pounds of nitrogen per acre per year for cropped acres in the Delaware River Basin (table 17). Nitrogen applications, including manure applications, account for 67 percent of the nitrogen sources in this region.

Model simulations show that about 69 percent of all nitrogen sources are taken up by the crop and removed at harvest in the crop yield (81.9 pounds per acre, on average), and the remainder is lost from the field through various pathways (table 17).[20]

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 48.5 pounds per acre. These nitrogen loss pathways are (fig. 23 and table 17)—

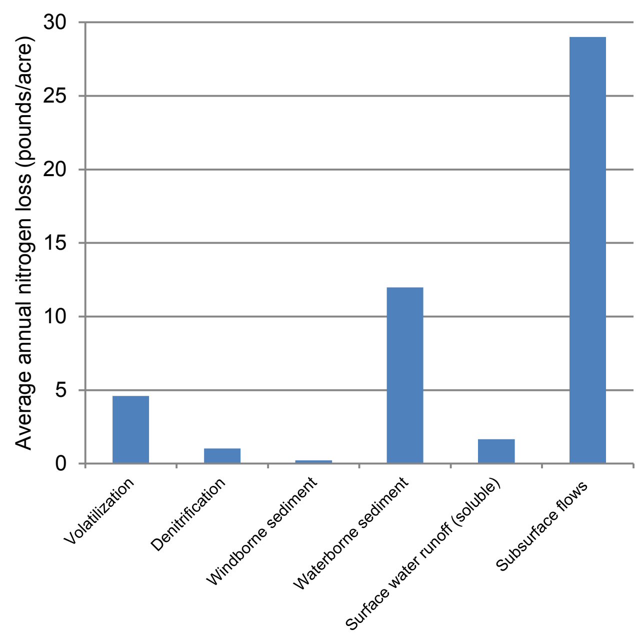
- nitrogen lost due to volatilization associated primarily with fertilizer and manure application (average of 4.6 pounds per acre per year);
- nitrogen returned to the atmosphere through denitrification (average of 1.0 pound per acre per year);
- nitrogen lost with windborne sediment (average of 0.2 pound per acre per year);
- nitrogen lost with surface runoff (average of 13.6 pounds per acre per year), consisting of nitrogen lost with waterborne sediment (average of 12.0 pounds per acre per year) and soluble nitrogen lost in surface runoff (average of 1.7 pounds per acre per year); and
- nitrogen loss in subsurface flow pathways (average of 29 pounds per acre per year).

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 24 and 25. Loss of nitrogen in subsurface flows is the dominant loss pathway for 78 percent of the cropped acres in the region. (The dominant loss pathway was determined for each sample point as the pathway with the highest loss.) Nitrogen lost with waterborne sediment is the dominant loss pathway for the remaining 22 percent.

Total nitrogen losses were higher for highly erodible acres than for non-highly erodible acres, even though the nitrogen sources were slightly higher, on average, for the non-highly erodible acres (table 17). The average total nitrogen loss for highly erodible acres was 59.5 pounds per acre per year, compared to 38.4 pounds per acre per year for non-highly erodible acres.

Figure 23. Average annual nitrogen loss by loss pathway, Delaware River Basin, baseline conservation condition



[20] A small amount may also build up in the soil or be mined from the soil, as shown in table 17 for the variable "change in soil nitrogen."

Table 17. Field-level effects of conservation practices on nitrogen sources and nitrogen loss pathways for cropped acres (845,600 acres) in the Delaware River Basin

Model simulated outcome	Average annual values in pounds per acre			
	Baseline conservation condition	No-practice scenario	Reduction due to practices	Percent reduction
All cropped acres				
Nitrogen sources				
Atmospheric deposition	8.6	8.6	0.0	0
Bio-fixation by legumes	30.6	29.1	-1.5	-5
Nitrogen applied as commercial fertilizer and manure	80.3	107.5	27.2	25
All nitrogen sources	119.5	145.2	25.7	18
Nitrogen in crop yield removed at harvest	81.9	90.0	8.1*	9
Nitrogen loss pathways				
Nitrogen loss by volatilization	4.6	4.6	-0.1**	-1
Nitrogen loss through denitrification	1.0	0.9	-0.1**	-16
Nitrogen lost with windborne sediment	0.2	0.3	0.1	31
Nitrogen loss with surface runoff, including waterborne sediment	13.6	20.7	7.0	34
Nitrogen loss with surface water (soluble)	1.7	4.5	2.9	63
Nitrogen loss with waterborne sediment	12.0	16.2	4.2	26
Nitrogen loss in subsurface flow pathways	29.0	43.0	14.0	33
Total nitrogen loss for all loss pathways	48.5	69.5	21.0	30
Change in soil nitrogen	-12.1	-15.4	-3.2	--
Highly erodible land (48 percent of cropped acres)				
All nitrogen sources	117.6	145.9	28.3	19
Total nitrogen loss for all loss pathways	59.5	87.1	27.5	32
Non-highly erodible land (52 percent of cropped acres)				
All nitrogen sources	121.3	144.6	23.3	16
Total nitrogen loss for all loss pathways	38.4	53.3	14.9	28

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

Figure 24. Cumulative distributions of average annual nitrogen lost through various loss pathways, Delaware River Basin, baseline conservation condition

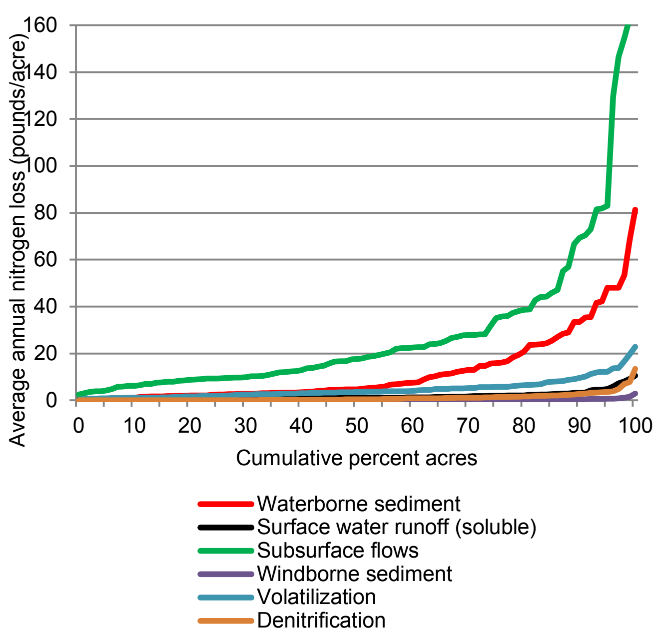
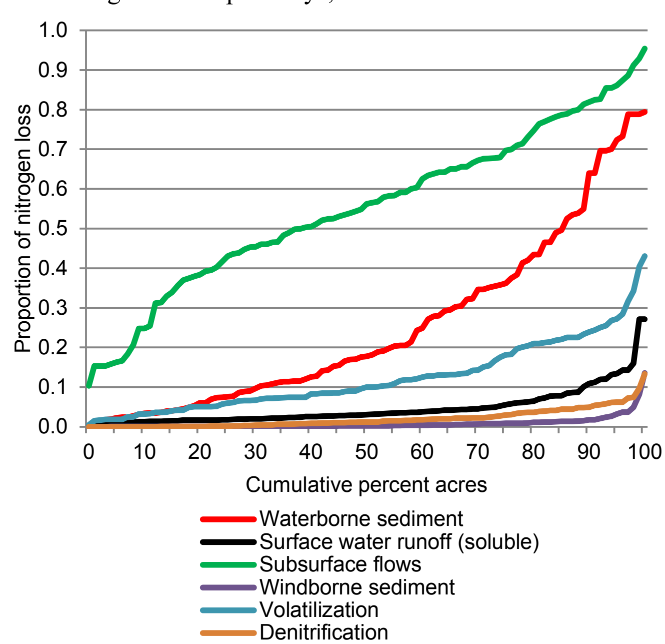


Figure 25. Cumulative distributions of proportions of nitrogen lost through six loss pathways, Delaware River Basin



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 *average annual* total nitrogen loss for the baseline is shown in figure 26. Acres with the highest nitrogen losses have the highest inherent vulnerability combined with inadequate nutrient management and runoff controls. About 56 percent of cropped acres lose, on average, less than 40 pounds per acre per year, while 9 percent lose 100 pounds or more per acre per year.

Model results for annual data indicate that some cropped acres in the Delaware River Basin are much more susceptible to the effects of weather than other acres and lose much higher amounts of nitrogen (fig. 27). Thirty percent of the acres lose less than 40 pounds per acre per year even in years with high levels of precipitation. Another 30 percent of the acres lose more than 100 pounds per acre in at least some years, and 20 percent lose more than 40 pounds per acre in every year. Figure 27 also shows that nitrogen loss for the 30 percent of the cropped acres with the highest losses varies significantly from year to year when compared to the 30 percent with the lowest total nitrogen loss.

Figure 26. Estimates of average annual total nitrogen loss for cropped acres in the Delaware River Basin

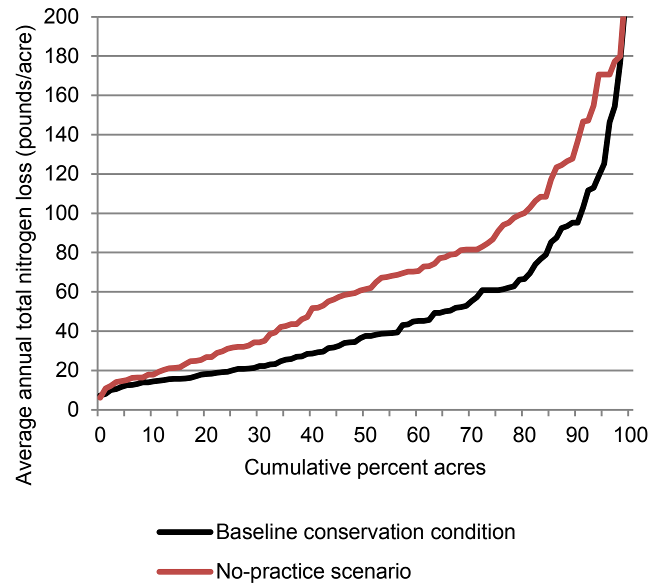
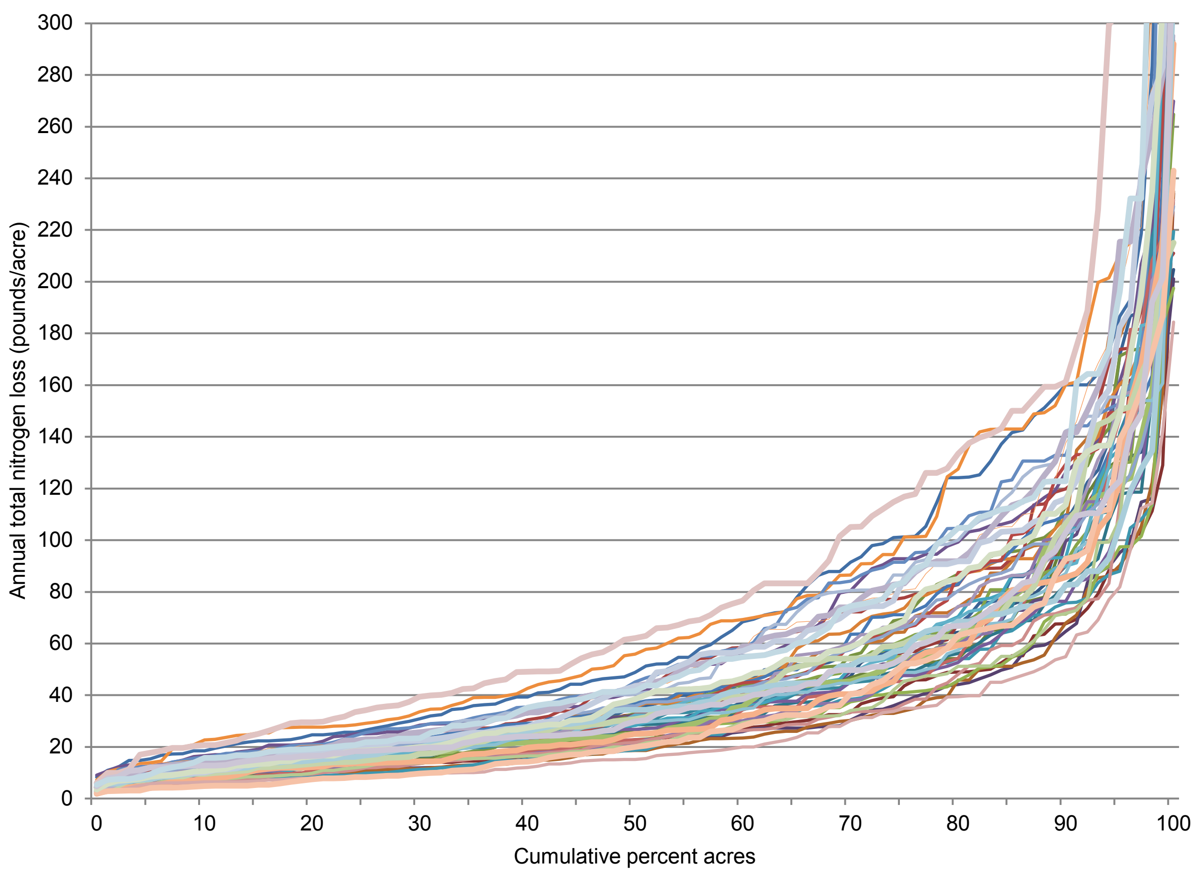


Figure 27. Distribution of annual total nitrogen loss for each year of the 47-year model simulation, Delaware River Basin



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 26 (above).

Effects of conservation practices on cropped acres

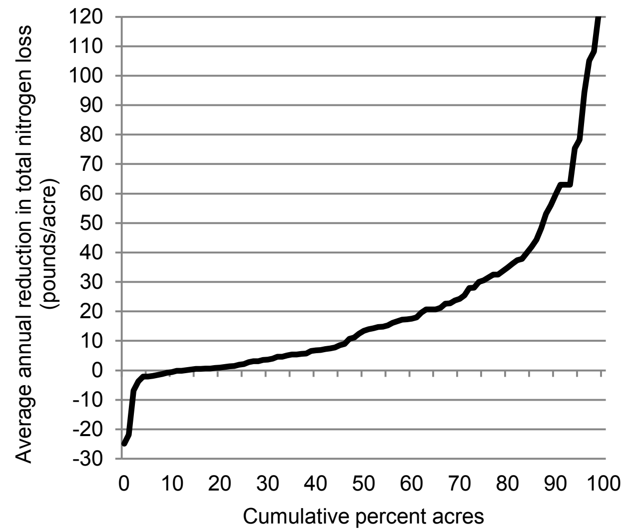
Total nitrogen loss, all pathways.
Model simulations show that the conservation practices in use in the region have reduced total nitrogen loss from cropped acres by an average of 21 pounds per acre per year, representing a 30-percent reduction, on average (table 17). Without conservation practices, about 67 percent of the cropped acres would have average annual total nitrogen loss exceeding 40 pounds per acre per year; with conservation practices, 43 percent of acres exceed this level of loss (fig. 26).

As shown in figure 28, the effects of conservation practices vary considerably, from acres with significant reductions due to practice use, to acres with little or no reductions, to acres with *increases* in nitrogen loss due to practices (negative reductions). About half of cropped acres have average annual reductions in total nitrogen loss above 10 pounds per acre per year due to conservation practice use. Fifteen percent have average annual reductions in total nitrogen loss above 40 pounds per acre per year due to conservation practice use. Acres with the highest reductions have higher levels of treatment and often higher levels of nitrogen use in the no-practice scenario.

In contrast, about 12 percent of the cropped acres have an average annual *increase* in total nitrogen loss due to conservation practice use. Most of these increases are small—less than 4 pounds per acre per year. They occur on soils with relatively high soil nitrogen content and generally low slopes where surface water runoff is redirected 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 can also result in small overall losses in total nitrogen due to conservation practice use. Cropping systems with legumes 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.

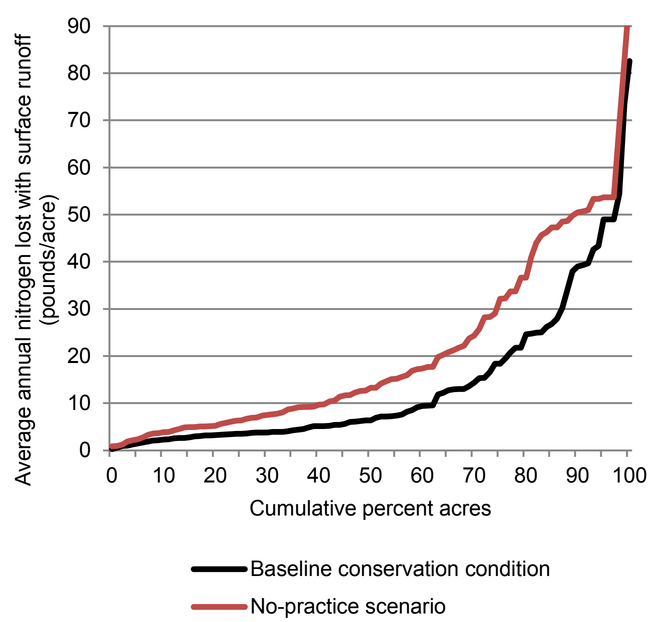
Nitrogen lost with surface runoff. Model simulations show that, on average, conservation practices have reduced nitrogen lost with surface runoff from 20.7 pounds per acre without practices to 13.6 pounds per acre with practices, a 34-percent reduction (table 17). Without conservation practices, about 47 percent of the cropped acres would lose more than 15 pounds per acre per year, on average, compared to 30 percent of the acres in the baseline conservation condition (fig. 29). Figure 30 shows that about 23 percent of cropped acres have reductions in nitrogen lost with surface runoff greater than 10 pounds per acre due to conservation practice use. In contrast, however, about 27 percent of the acres have reductions less than 2 pounds per acre due to conservation practices.

Figure 28. Estimates of average annual reduction in total nitrogen loss due to the use of conservation practices on cropped acres in the Delaware River Basin



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 12 percent of the acres.

Figure 29. Estimates of average annual nitrogen lost with surface runoff (including waterborne sediment) for cropped acres in the Delaware River Basin

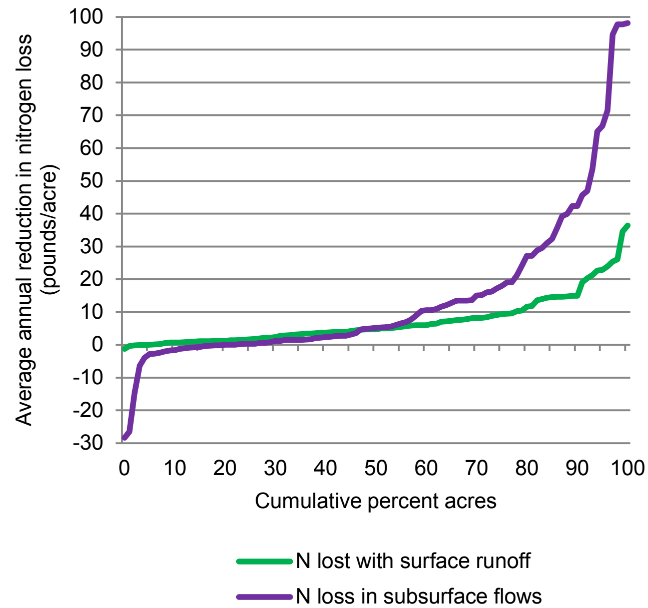


Nitrogen loss in subsurface flows. Conservation practices are effective in reducing nitrogen loss in subsurface flows on some acres in this region, but make little difference on other acres and even result in increases in nitrogen loss in subsurface flows for 15 percent of cropped acres (figs. 30 and 31). (Increases in nitrogen loss in subsurface flows are represented in figure 30 as negative reductions.) On average, conservation practices have reduced nitrogen loss in subsurface flows from 43 pounds per acre without practices to 29 pounds per acre with practices, representing an average reduction of 14 pounds per acre per year—a 33-percent reduction (table 17). Figure 30 shows that reductions in average annual nitrogen loss in subsurface flows exceed 10 pounds per acre for 42 percent of the cropped acres.

The increases in nitrogen loss in subsurface flows due to conservation practices on 15 percent of the cropped acres (fig. 30) 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 positive effects of conservation practices on other nitrogen loss pathways.

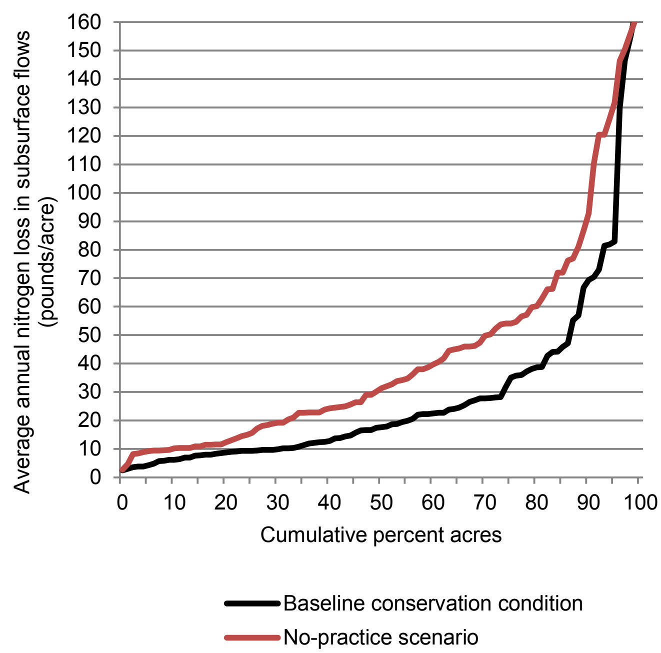
These model simulation results underscore the importance of pairing water erosion control practices with effective nutrient management practices so that the full suite of conservation practices will provide the environmental protection needed.

Figure 30. 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 Delaware River Basin



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

Figure 31. Estimates of average annual nitrogen loss in subsurface flows for cropped acres in the Delaware River Basin



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 seeps at the lower part of the field. The planned practices will solve the erosion problem, but could exacerbate the 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.
- Implementation of a nutrient management plan may reduce the amount of manure added to a field and thus reduce the loss of nutrients to surface or groundwater. However, this reduction in organic material added to the field may also reduce the soil organic matter or reduce the rate of change in soil organic matter.
- Figure 28 shows that about 12 percent of the acres have an increase in total nitrogen loss due to conservation practice use, although most of these increases are small. 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 Practices on Phosphorus Loss

Phosphorus, like nitrogen, is an essential element needed for crop growth. Unlike nitrogen, phosphorus rarely occurs in a gaseous form so the agricultural model has no atmospheric component. 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.

Throughout this report, phosphorus results are reported in terms of elemental phosphorus (i.e., not as the phosphate fertilizer equivalent).

Baseline condition for cropped acres

In the model simulations for the Delaware River Basin, about 21 pounds per acre of phosphorus were applied as commercial fertilizer or with manure to cropped acres, on average, in each year of the model simulation (table 18). About 61 percent of the phosphorus applied is taken up by the crop and removed at harvest—12.7 pounds per acre per year, on average.

Total phosphorus loss for all loss pathways averaged 4.4 pounds per acre per year in the baseline conservation condition (table 18). These phosphorus loss pathways are—

- phosphorus lost with windborne sediment (average of less than 0.1 pound per acre per year);
- phosphorus lost with waterborne sediment (average of 2.6 pound 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 1.7 pounds per acre per year); and
- soluble phosphorus that percolates through the soil profile into the groundwater (average of 0.1 pound per acre per year).

Nearly all of the phosphorus is lost from farm fields through the two principal loss pathways in the Delaware River Basin—phosphorus attached to soil particles in waterborne sediment (58 percent of total loss, on average) and soluble phosphorus lost to surface water (39 percent of total loss, on average) (fig. 32, table 18). Phosphorus lost with wind erosion accounts for about 1 percent. The percentage of phosphorus lost in each of the principal loss pathways varies from acre to acre, as shown in figure 33 for cropped acres.

Phosphorus lost with waterborne sediment is the dominant loss pathway for 54 percent of cropped acres. (The dominant loss pathway was determined for each sample point as the pathway with the highest loss.) Soluble phosphorus lost with surface water runoff and lateral flow (including discharge to drainage tiles, ditches, and seeps) was the dominant loss pathway for 46 percent of cropped acres.

Phosphorus losses are twice as high for highly erodible land as for non-highly erodible land (table 18). Phosphorus losses on the 48 percent of the cropped acres that are highly erodible average 6 pounds per acre per year compared to 3 pounds per acre per year for non-highly erodible acres.

Figure 32. Estimates of average annual phosphorus lost through various loss pathways, Delaware River Basin, baseline conservation condition

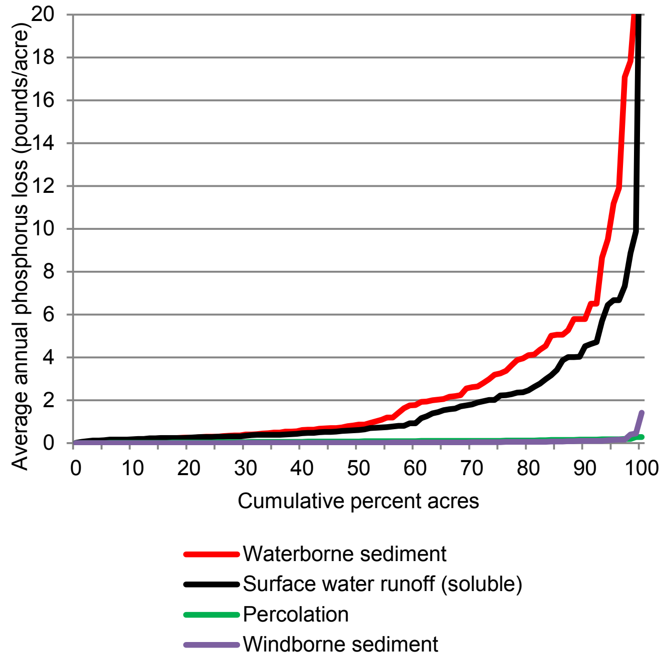
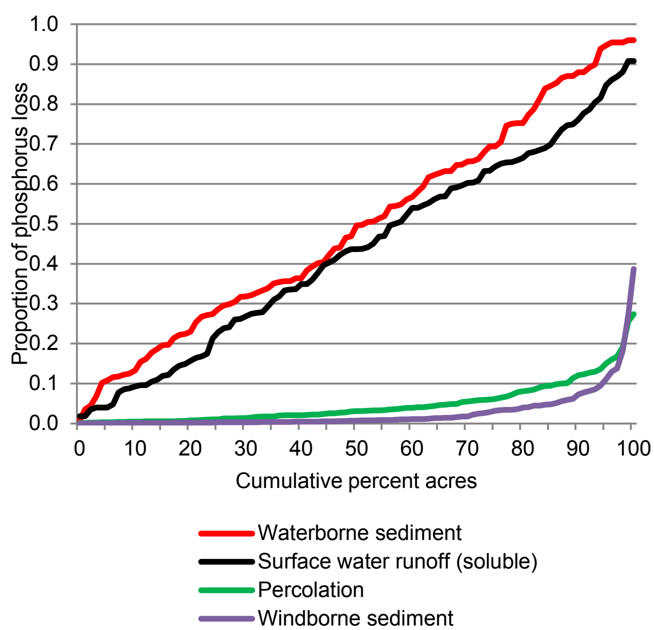


Figure 33. Cumulative distributions of the proportion of phosphorus lost through various loss pathways, Delaware River Basin, baseline conservation condition



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.

Table 18. Field-level effects of conservation practices on phosphorus sources and phosphorus loss pathways for cropped acres (845,600 acres) in the Delaware River Basin

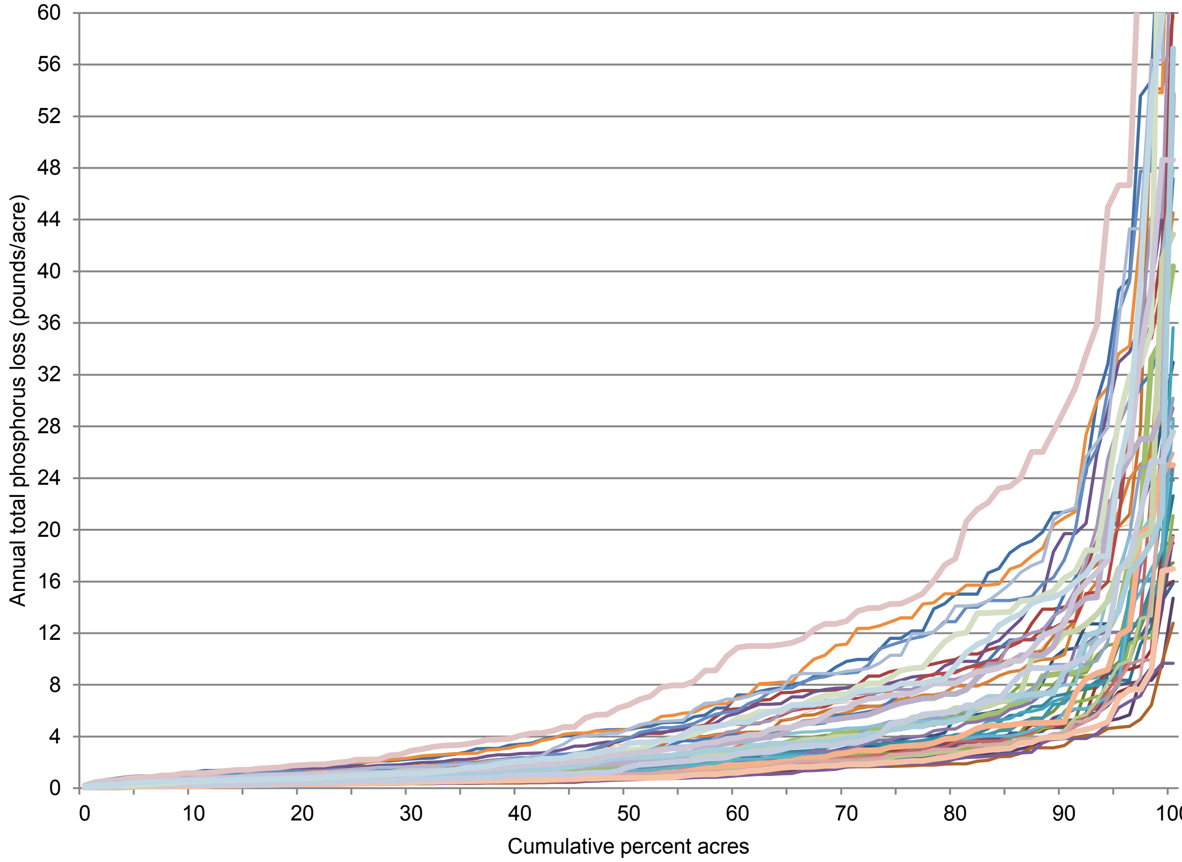
	Average annual values in pounds per acre			
Model simulated outcome	Baseline conservation condition	No-practice scenario	Reduction due to practices	Percent reduction
All cropped acres				
Phosphorus sources				
Phosphorus applied as commercial fertilizer and manure	20.9	29.8	8.9	30
Phosphorus in crop yield removed at harvest	12.7	13.8	1.0	8
Phosphorus loss pathways				
Phosphorus lost with windborne sediment	<0.1	0.1	0.1	52
Phosphorus lost to surface water (sediment attached and soluble)*	4.3	7.4	3.1	42
Soluble phosphorus lost to surface water*	1.7	2.8	1.1	40
Phosphorus loss with waterborne sediment	2.6	4.5	1.9	43
Soluble phosphorus loss to groundwater	0.1	0.1	0.0	0
Total phosphorus loss for all loss pathways	4.4	7.6	3.1	41
Change in soil phosphorus	3.7	8.5	4.8	--
Highly erodible land (48 percent of cropped acres)				
Phosphorus applied as commercial fertilizer and manure	22.8	30.5	7.7	25
Total phosphorus loss for all loss pathways	6.0	10.2	4.3	42
Non-highly erodible land (52 percent of cropped acres)				
Phosphorus applied as commercial fertilizer and manure	19.2	29.2	10.0	34
Total phosphorus loss for all loss pathways	3.0	5.1	2.1	41

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

Total phosphorus loss varies considerably from year to year and from acre to acre, as shown in figure 34. About 40 percent of the acres lose less than 4 pounds per acre per year through the various loss pathways under *all* weather conditions (fig. 34). In contrast, about one-third of the acres lose more than 12 pounds per acre in at least some years. Phosphorus losses can exceed 40 pounds per acre in some years on up to 6 percent of cropped acres.

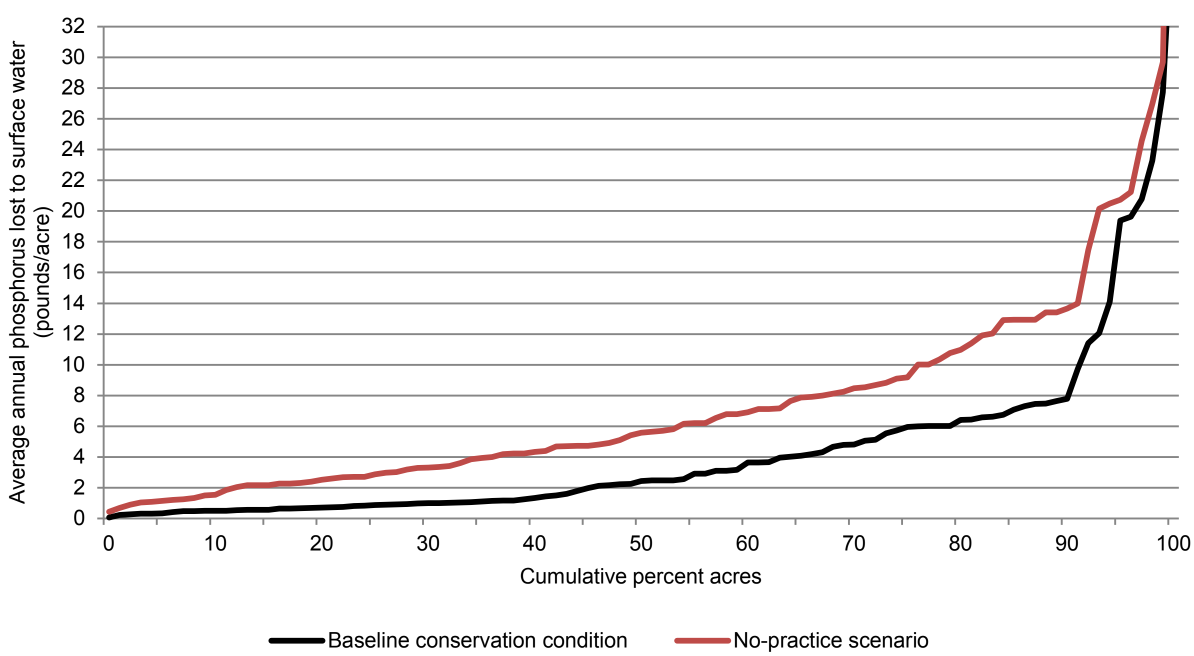
The *average annual* phosphorus lost to surface water for the baseline is shown in figure 35. Acres with the highest phosphorus losses have the highest inherent vulnerability combined with inadequate nutrient management and runoff controls. About 63 percent of cropped acres lose, on average, less than 4 pounds per acre per year, while 8 percent lose 10 pounds or more per acre per year.

Figure 34. Distribution of annual total phosphorus loss for each year of the 47-year model simulation, Delaware River Basin



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 35. Estimates of average annual phosphorus lost to surface water (sediment attached and soluble)* for cropped acres in the Delaware River Basin



* 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

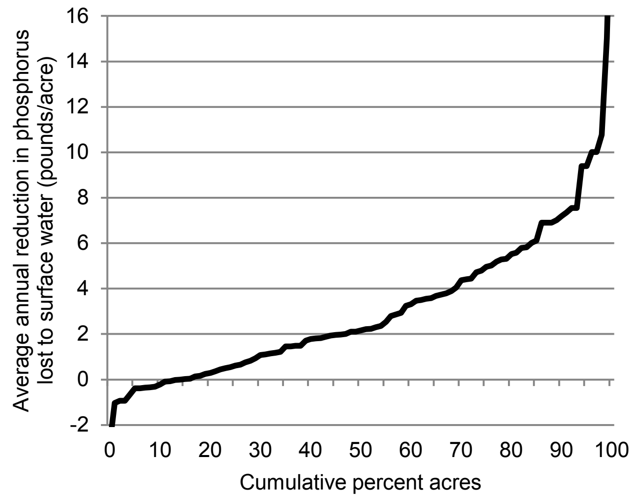
Conservation practices have reduced phosphorus lost to surface water for cropped acres by 42 percent, reducing the average loss from 7.4 pounds per acre per year if conservation practices were not in use to 4.3 pounds per acre per year for the baseline conservation condition (table 18). The average reduction is greater for phosphorus lost with waterborne sediment than for soluble phosphorus loss, but the average percent reduction is about the same. On average, conservation practices have reduced phosphorus loss with waterborne sediment by 43 percent and soluble phosphorus lost to surface water by 40 percent (table 18).

The effects of conservation practices on phosphorus lost to surface water (soluble and sediment attached) are shown in figures 35 and 36 for cropped acres. Without conservation practices in use, 64 percent of cropped acres would exceed 4 pounds per acre per year of phosphorus lost to surface water, on average, compared to 37 percent with conservation practice use as represented in the baseline conservation condition (fig. 35).

The effects of conservation practices on phosphorus lost to surface water vary considerably throughout the Delaware River Basin, as shown in figure 36. At the high end, reductions exceed 5 pounds per acre for about 24 percent of the acres. These are acres with higher levels of treatment and often higher levels of phosphorus use in the no-practice scenario.

For about 12 percent of the acres, however, conservation practice use results in *increases* in phosphorus lost to surface water, although the increases exceed 0.5 pound per acre for only 4 percent of the acres. (Increases in phosphorus lost to surface water are represented in figure 36 as negative reductions.) In some cases these increases in phosphorus loss are the result of small increases in surface water runoff due to conservation practice use (see fig. 14 and associated footnote). In other cases, however, increases in phosphorus loss due to conservation practices resulted from a combination of practices and landscape conditions that cause phosphorus levels to concentrate near or on the soil surface, where it is more vulnerable to surface runoff. On these types of landscapes, improved phosphorus management along with light incorporation and maintenance of crop residue on the soil surface may be necessary to reduce soluble phosphorus loss.

Figure 36. Estimates of average annual reduction in phosphorus lost to surface water (sediment attached and soluble) due to conservation practices on cropped acres in the Delaware River Basin



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 may 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.

Model simulations incorporated pesticide use information from the CEAP survey conducted in 2003–06 (active ingredient, application rate, application method, and time of application). A total of 78 different pesticides are used in the region, as reported in the survey. The most commonly applied pesticides are presented in table 19. The three pesticides applied in the largest amount for the entire region were the herbicides atrazine, glyphosate isopropylamine salt, and S-metolaclor, together accounting for 60 percent of the total weight of all pesticides applied. Other pesticides each represented 6 percent or less of the total weight of pesticides applied in the region.

Baseline condition for pesticide loss

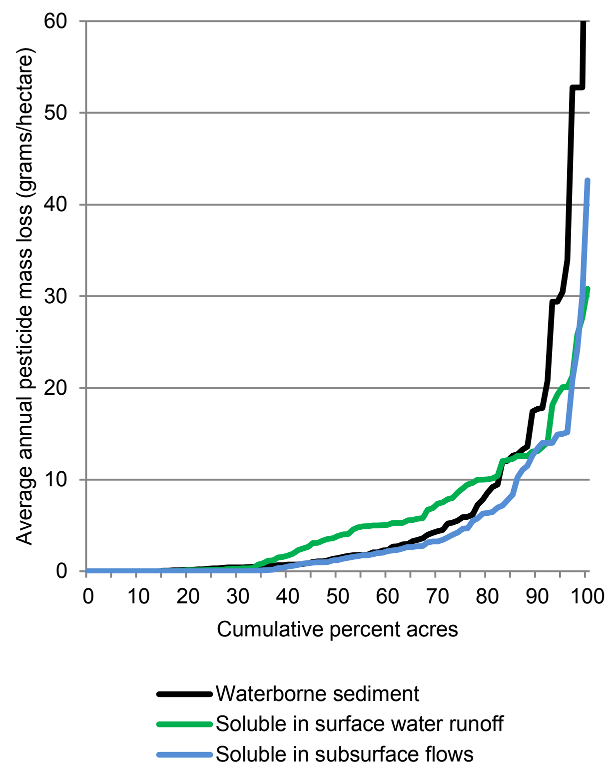
The APEX model tracks the mass loss of pesticides dissolved in surface water runoff, adsorbed to sediment lost through water erosion, and dissolved in subsurface flow pathways.[21] The distribution of losses through each of these three pathways is contrasted in figure 37. All three pathways are important in the transport of pesticide residues from fields.

The dominant loss pathway for 42 percent of cropped acres was pesticides lost with waterborne sediment. (The dominant loss pathway was determined for each sample point as the pathway with the highest loss.) Surface water runoff was the dominant pesticide loss pathway for 34 percent of the acres, and subsurface flows were the dominant pesticide loss pathway for 17 percent of the acres. The remaining 7 percent of the acres had no pesticide loss.

The average annual amount of pesticide lost from farm fields in the Delaware River Basin is about 16 grams of active ingredient per hectare per year (table 20).[22] As was observed for sediment and nutrient loss, the majority of pesticide loss occurs on a minority of acres within the Delaware River Basin (fig. 37). The median loss is only 9 grams per hectare.

The most common pesticide residues lost from farm fields in model simulations are the herbicides atrazine (37 percent of total mass loss), pendamethalin (16 percent of total mass loss, glyphosate isopropylamine salt (14 percent of total mass loss), and S-metolachlor (10 percent of total mass loss) (table 19). These four pesticides account for 77 percent of all pesticide residues lost from fields in the model simulations for the Delaware River Basin.

Figure 37. Estimates of average annual pesticide loss (mass loss of all pesticides combined) for three loss pathways, Delaware River Basin, baseline conservation condition



[21] The APEX model currently does not estimate pesticides lost in spray drift, volatilization, or with windblown sediment.

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

Table 19. Dominant pesticides applied in model simulations and contributing to losses, Delaware River Basin

Pesticide (active ingredient name)	Pesticide type	Percent of total applied in the region
Pesticide application*		
Atrazine	Herbicide	26
Glyphosate, isopropylamine salt	Herbicide	20
S-Metolachlor	Herbicide	14
Pendimethalin	Herbicide	6
Metolachlor	Herbicide	4
Acetochlor	Herbicide	4
Chlorpyrifos	Insecticide	4
Chlorothalonil	Fungicide	3
Glyphosate	Herbicide	2
Simazine	Herbicide	2
Paraquat dichloride	Herbicide	2
Alachlor	Herbicide	2
Methomyl	Insecticide	2
Glyphosate-trimesium	Insecticide	2
Total		93
		Percent of total pesticide loss in the region**
Pesticide loss from farm fields*		
Atrazine	Herbicide	37
Pendimethalin	Herbicide	16
Glyphosate, isopropylamine salt	Herbicide	14
S-Metolachlor	Herbicide	10
Metolachlor	Herbicide	6
Acetochlor	Herbicide	3
Paraquat dichloride	Herbicide	2
Simazine	Herbicide	2
Copper hydroxide	Fungicide	1
2,4-D, 2-ethylhexyl ester	Herbicide	1
Chlorothalonil	Fungicide	1
Sulfentrazone	Herbicide	1
Total		94

* Pesticides not listed each represented less than 1 percent of the total mass weight applied or lost in the region. 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.

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

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)	1,598	1,993	395	20
Pesticide loss				
Average annual mass loss of pesticides for all pathways (grams of active ingredient/hectare)	15.7	24.7	9.0	36
Edge-of-field pesticide risk indicator				
Average annual surface water pesticide risk indicator for aquatic ecosystems	1.97	3.02	1.05	35
Average annual surface water pesticide risk indicator for humans	0.38	0.51	0.14	27
Average annual groundwater pesticide risk indicator for humans	0.40	0.55	0.15	27

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

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 Pest 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 in the Delaware River Basin. Use of conservation practices has reduced the loss of pesticides (summed over all pesticides) by an average of 9 grams of active ingredient per hectare per year, a 36-percent reduction from the 24.7 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 average annual 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 78 pesticides included in the model for the Delaware River Basin.[23]

Risk indicator values of less than 1 are considered "safe" because the annual average concentration is below the toxicity threshold for exposure at the edge of the field.[24]

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 21). Based on the model simulations, the edge-of-field risk indicator for atrazine exceeded 1 for 37 percent of the cropped acres for risk to aquatic ecosystems, 8 percent of the cropped acres for surface water risk to humans, and 10 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).

Figure 38 shows that for most years the overall risk for aquatic ecosystems is low, in part because of the conservation practices in use. Figure 39 shows that 30 percent of cropped acres have an average value less than 0.1 for the pesticide risk indicator for aquatic ecosystems. But the edge-of-field concentrations can be high relative to "safe" thresholds for some acres in some years. The pesticide risk indicator for aquatic ecosystems averaged 1.97 over all years and cropped acres (table 20) for the baseline conservation condition. (The 1.97 value indicates that average annual pesticide concentrations in water leaving cropped fields in the Delaware River Basin are 1.97 times the "safe" concentration for non-target plant and animal species when exposed to concentrations at the edge of the field.) The median value, however, is only 0.97 (fig. 39).

---

[23] For a complete documentation of the development of the pesticide risk indicators, see the documentation report "Pesticide risk indicators used in the CEAP cropland modeling," referenced on page 5.

[24] 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.

Pesticide Risk Indicators

Three ***edge-of-field*** pesticide risk indicators were used 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.

Pesticide risk indicators were calculated for each pesticide as the ratio of the concentration in water leaving the field to the "safe" concentration (toxicity thresholds) for each pesticide, where both are expressed in units of parts per billion. This ratio is called the Aquatic Risk Factor (ARF). ARFs are unit-less numbers that represent the relative toxicity of pesticides in solution. A risk indicator value of less than 1 is considered "safe" because the concentration is below the toxicity threshold for exposure at the edge-of-the field.

$$ARF = \frac{\text{(Annual Concentration)}}{\text{(Toxicity Threshold)}} < 1 \quad \rightarrow \text{Little or no potential adverse impact}$$

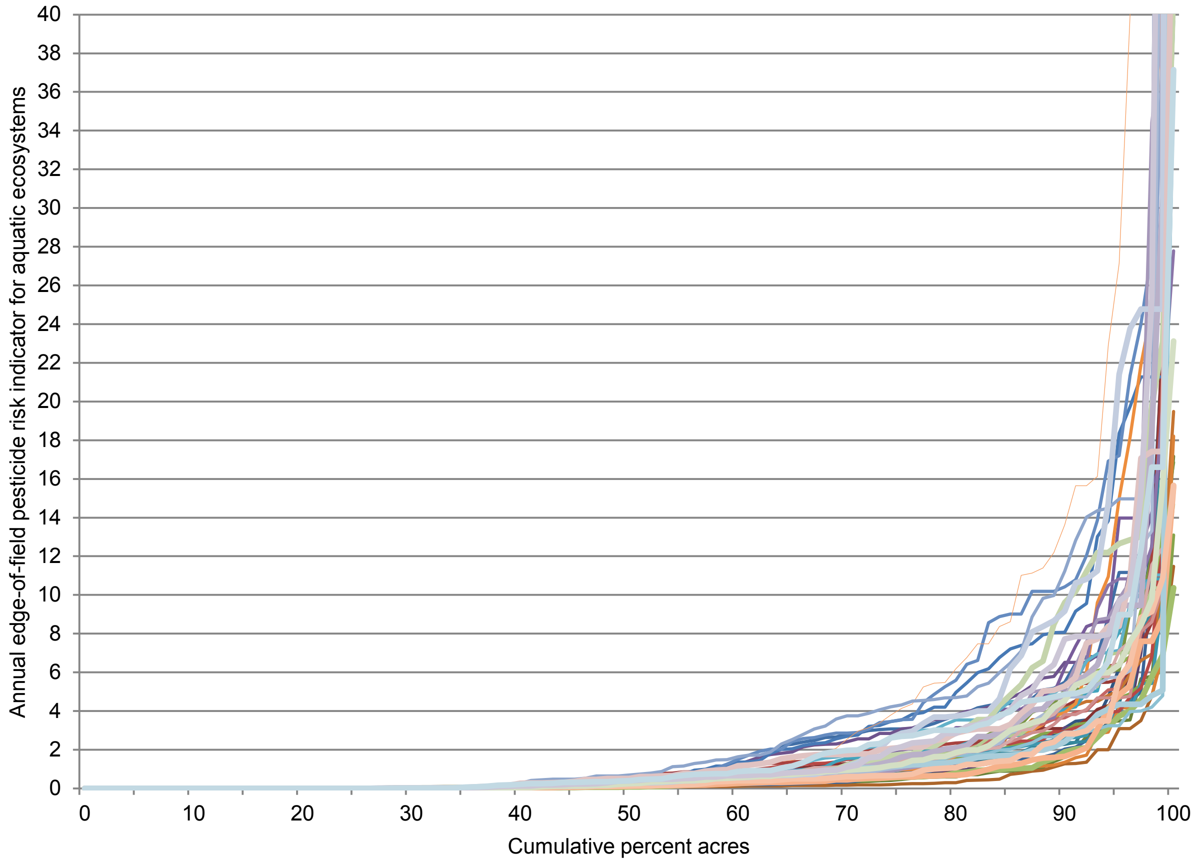
Two aquatic toxicity thresholds were used in estimating potential risk:

- Human drinking water lifetime toxicity thresholds. These thresholds are either taken from the EPA Office of Water Standards, or derived from EPA Reference Doses or Cancer Slopes using the methods employed by the EPA Office of Water.
- Aquatic ecosystem toxicity thresholds. The lowest (most sensitive) toxicity is used from the fish chronic NOEL (No Observable Effect Concentration), invertebrate chronic NOEL, aquatic vascular plant acute EC50 (Effective Concentration that is lethal to 50 percent of the population) and aquatic nonvascular plant acute EC50.

Table 21. Pesticides determining edge-of-field environmental risk, Delaware River Basin

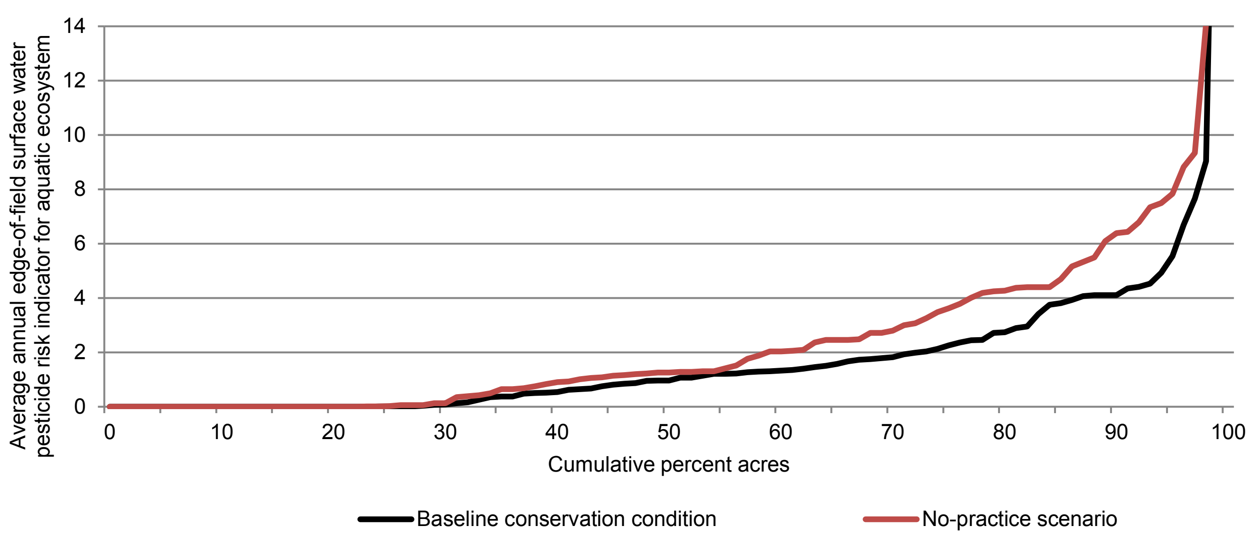
Pesticide (active ingredient name)	Pesticide type	Percent of cropped acres in the region with average annual edge-of-field risk indicator greater than 1
Risk indicator for aquatic ecosystem		
Atrazine	Herbicide	37
Metolachlor	Herbicide	6
2,4-D, 2-ethylhexyl ester	Herbicide	4
Acetochlor	Herbicide	2
Parathion	Insecticide	1
Sulfentrazone	Herbicide	1
Chlorpyrifos	Insecticide	1
All other pesticides combined		2
Risk indicator for humans, surface water		
Atrazine	Herbicide	8
Simazine	Herbicide	<1
Risk indicator for humans, groundwater		
Atrazine	Herbicide	10

Figure 38. 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, Delaware River Basin



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.

Figure 39. Estimates of average annual edge-of-field surface water pesticide risk indicator for aquatic ecosystem in the Delaware River Basin



The pesticide risk indicators for humans were much lower, averaging 0.38 for surface water and 0.40 for groundwater in the baseline conservation condition (table 20). The median values are 0.25 for surface water and 0.34 for groundwater. About 9 percent of the cropped acres have an average annual edge-of-field surface water pesticide risk indicator for humans greater than 1 for the baseline conservation condition (fig. 40).

The use of conservation practices in the Delaware River Basin has reduced the pesticide risk indicator for aquatic ecosystems by 35 percent (table 20), averaged over all years, all pesticides, and all cropped acres. Both the surface water pesticide risk indicator and the groundwater pesticide risk indicator for humans have been decreased by 27 percent due to conservation practice use (table 20).

Figure 41 shows the distribution of the reductions due to conservation practices in the two surface water pesticide risk indicators. Significant risk reductions for aquatic ecosystems occur on about 35 percent of the acres, while significant risk reductions for humans occur on only about 10 percent of the acres. The benefits of conservation practices were significant for both aquatic ecosystem risks and human risks on the acres that had those risks, but because aquatic ecosystem risks were more widespread than human risks, conservation practices have greater potential benefit for aquatic ecosystems than for human drinking water.

Figure 40. Estimates of average annual edge-of-field surface water pesticide risk indicator for humans in the Delaware River Basin

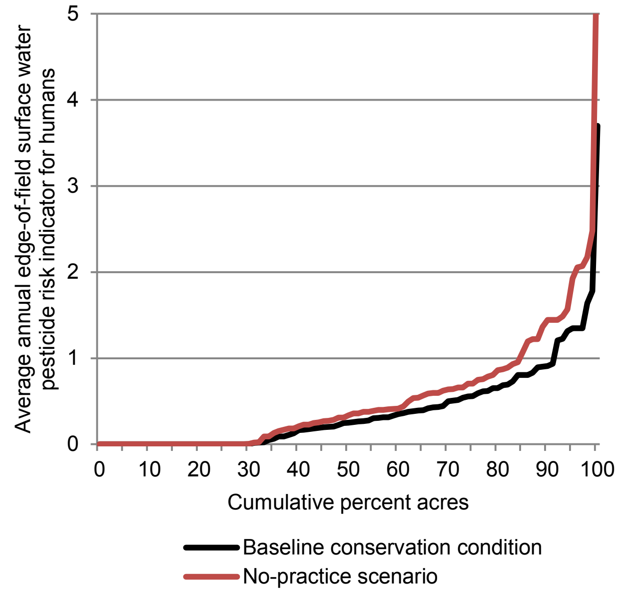
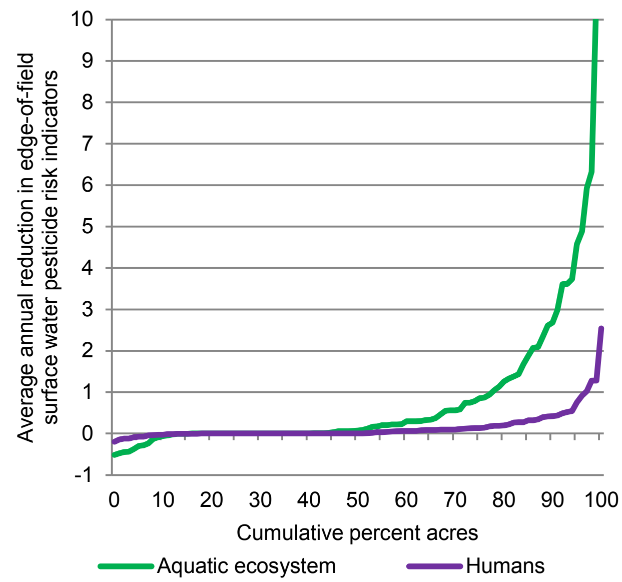


Figure 41. Estimates of average annual reductions in the edge-of-field surface water pesticide risk indicators for aquatic ecosystems in the Delaware River Basin



Note: Negative reductions in pesticide loss (and therefore risk) similar to negative reductions in soluble phosphorus losses occur on some landscapes as a result of reduced tillage (see discussion related to figure 36 on phosphorus reductions.)

Chapter 5
Assessment of Conservation Treatment Needs

The adequacy of conservation practices in use in the Delaware River Basin was evaluated to identify remaining conservation treatment needs for controlling water erosion 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 region indicate that—

- 51.3 percent of cropped acres (434,212 acres) have a **high** level of need for additional conservation treatment,
- 22.4 percent of cropped acres (189,276 acres) have a **moderate** level of need for additional conservation treatment, and
- 26.3 percent of cropped acres (222,113 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 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. 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 permeable 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.

The 623,487 acres with additional conservation treatment needs—undertreated acres—were identified by an imbalance between the level of conservation treatment and the level of inherent vulnerability. Derivation of conservation treatment levels and inherent soil vulnerability classes are described in the next two sections, followed by estimates of undertreated acres.

Conservation Treatment Levels

Drawing from the evaluation of practice use presented in chapter 3, four levels of conservation treatment (high, moderately high, moderate, and low) were defined. 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 Delaware River Basin.

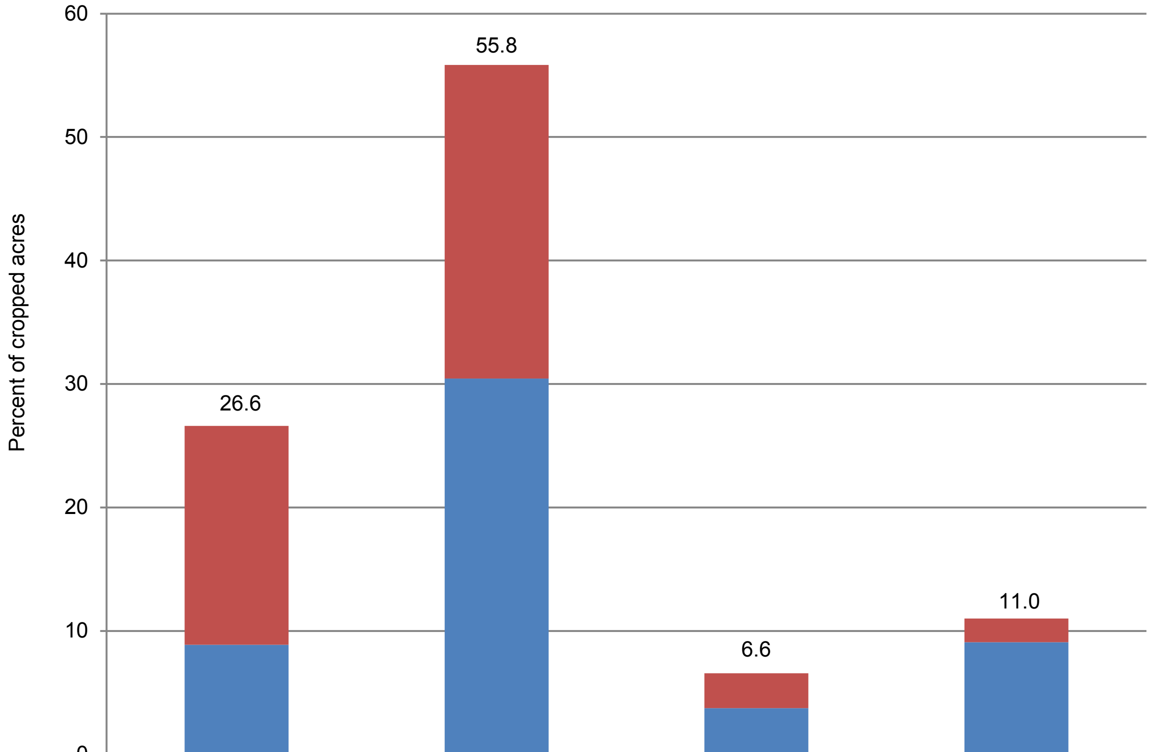
For sediment loss due to water erosion, conservation treatment levels were defined by a combination of structural practices and residue and tillage management practices, as defined in figure 42. A high level of water erosion control treatment is in use on about 11 percent of cropped acres, primarily on non-highly erodible land. About 7 percent have a moderately high level of conservation treatment. About 56 percent of cropped acres have a moderate level of conservation treatment for water erosion control, including the majority of the highly erodible land. The remaining 27 percent of cropped acres have a low level of conservation treatment for water erosion control. Thus, nearly 83 percent of cropped acres have only a low or moderate level of treatment, including 90 percent of highly erodible land.

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 43. A high level of treatment for nitrogen runoff is in use on only 1 percent of cropped acres. About 17 percent have a moderately high level of conservation treatment. The bulk of cropped acres—62 percent—have combinations of practices that indicate a moderate level of treatment. About 20 percent of cropped acres have a low level of treatment for nitrogen runoff.

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 44. A high level of treatment for phosphorus runoff is in use on only 3 percent of the acres. About 24 percent of cropped acres have combinations of practices that indicate a moderately high level of treatment. About 41 percent of cropped acres have a moderate level of treatment, and 32 percent of cropped acres have a low level of phosphorus management.

The nitrogen management level presented in figure 7 (see chapter 3) was used to evaluate the adequacy of conservation treatment for nitrogen loss in subsurface flows. A high level of treatment for nitrogen loss in subsurface flows is in use on 13 percent of the acres, and about 34 percent of cropped acres have a moderately high level of treatment. About 35 percent of cropped acres have a moderate level and 18 percent have a low level of nitrogen treatment.

Figure 42. Percent of cropped acres at four conservation treatment levels for water erosion control in the baseline conservation condition, Delaware River Basin



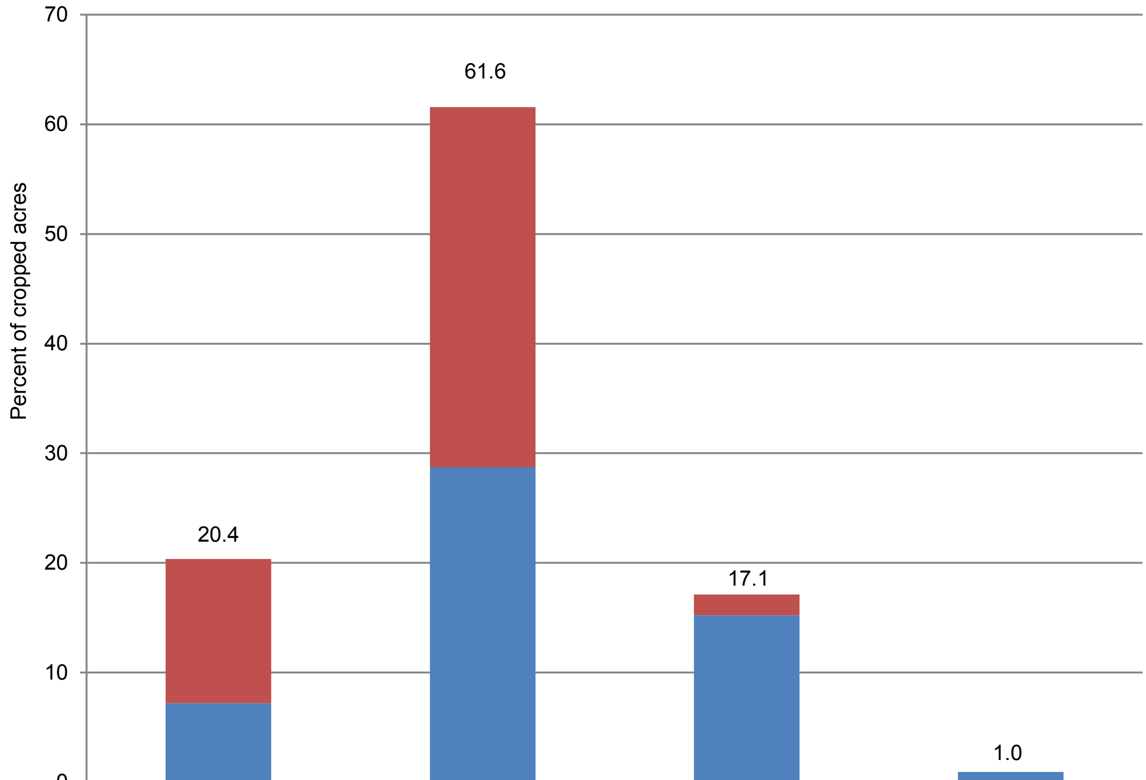
	Low	Moderate	Moderately high	High
HEL	17.7	25.4	2.8	1.9
Non-HEL	8.9	30.4	3.7	9.1

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. 5 and 6). 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 48 percent of cropped acres in the Delaware River Basin are highly erodible land (HEL).

Figure 43. Percent of cropped acres at four conservation treatment levels for nitrogen runoff control in the baseline conservation condition, Delaware River Basin



	Low	Moderate	Moderately high	High
HEL	13.1	32.8	1.9	0.0
Non-HEL	7.2	28.7	15.2	1.0

Criteria were derived using a combination of structural practice treatment levels, residue and tillage management treatment levels, and nitrogen management treatment levels (see figs. 5-7). 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:

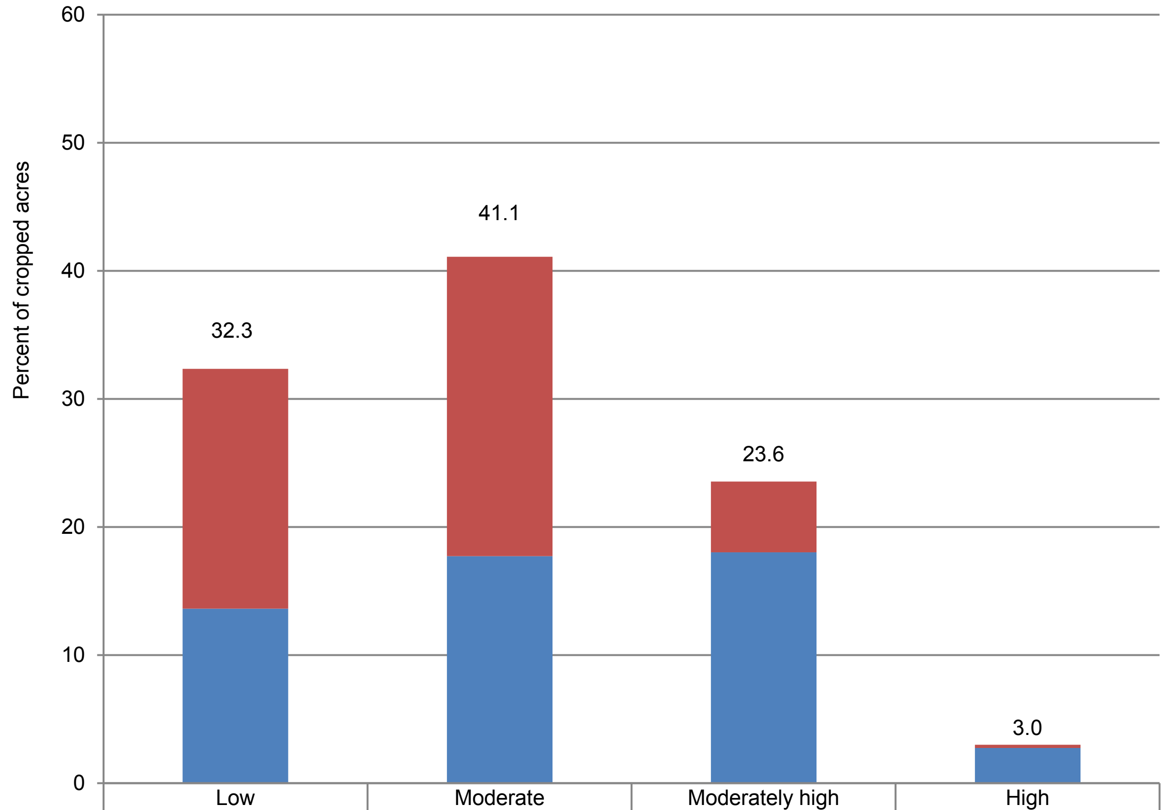
- **High treatment**: Sum of residue and tillage management score and nitrogen management score is equal to 8. (High treatment level for both structural practices and nitrogen management practices).
- **Moderately high treatment**: Sum of scores equal to 6 or 7.
- **Moderate treatment**: Sum of scores 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 48 percent of cropped acres in the Delaware River Basin are highly erodible land (HEL).

Figure 44. Percent of cropped acres at four conservation treatment levels for phosphorus runoff control in the baseline conservation condition, Delaware River Basin



	Low	Moderate	Moderately high	High
HEL	18.7	23.4	5.5	0.2
Non-HEL	13.6	17.7	18.0	2.8

Criteria were derived using a combination of structural practice treatment levels, residue and tillage management treatment levels, and phosphorus management treatment levels (see figs. 5, 6, and 8) 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 48 percent of cropped acres in the Delaware River Basin are highly erodible land (HEL).

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 soil erodibility (the water erosion equation K-factor). Inherent vulnerability factors for loss of nutrients in subsurface flows include soil properties that promote infiltration—soil hydrologic group, slope, water erosion equation 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 United States to allow for regional comparisons. Thus, some soil vulnerability potentials are not well represented in every region.

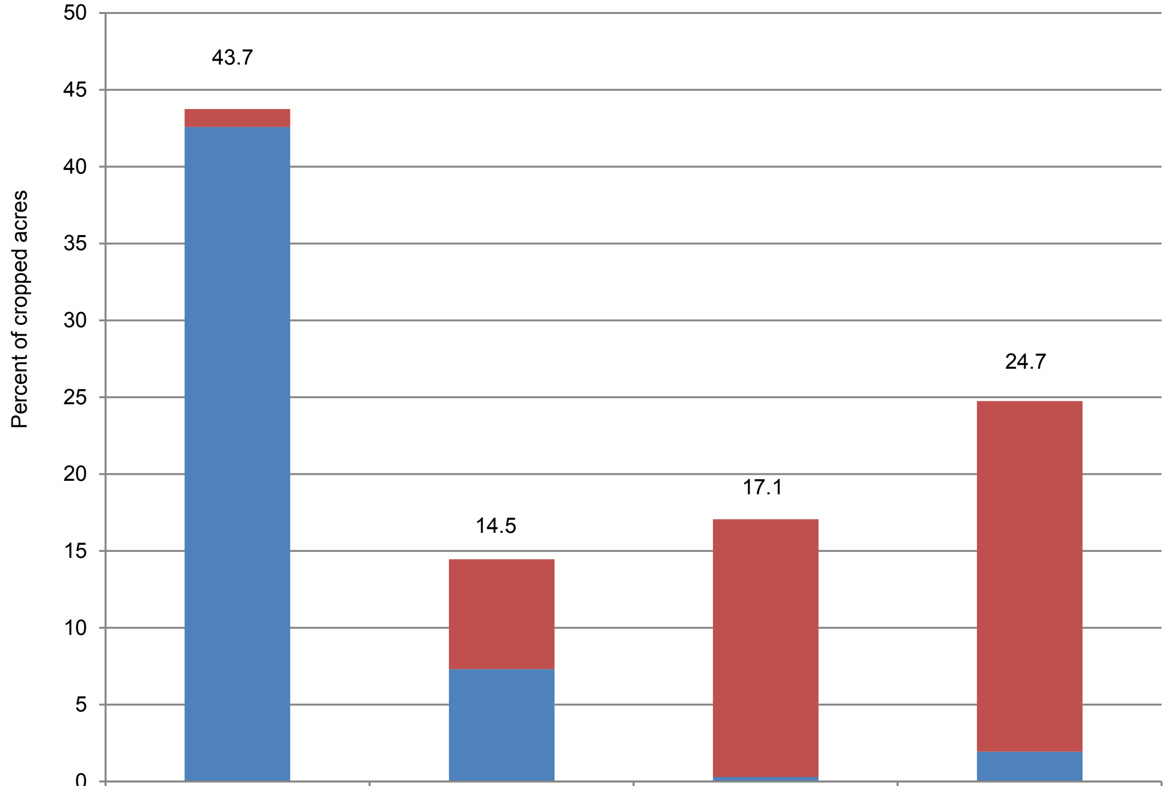
The criteria for the soil runoff potential are presented in figure 45, followed by the spatial distribution of the soil runoff potential within the Delaware River Basin in figure 46. The criteria and spatial distribution for the soil leaching potential are presented in figures 47 and 48.

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

About 44 percent of cropped acres have a low soil runoff potential in this region, consisting mostly of non-highly erodible land (fig. 45). In contrast, 25 percent of cropped acres have a high level of soil runoff potential and 17 percent have a moderately high level. The remaining 14 percent have a moderate soil runoff potential.

Very few acres (3 percent) have a low level of vulnerability to leaching in this region. The majority of cropped acres—52 percent—have a moderate soil leaching potential (figs. 47 and 48). The remaining 45 percent of cropped acres have either a high or moderately high soil leaching potential, including the majority of the highly erodible land in the region.

Figure 45. Soil runoff potential for cropped acres in the Delaware River Basin



	Low	Moderate	Moderately high	High
HEL	1.2	7.1	16.8	22.8
Non-HEL	42.6	7.3	0.3	1.9

Criteria for four classes of soil runoff potential were derived using a combination of soil hydrologic group, percent 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

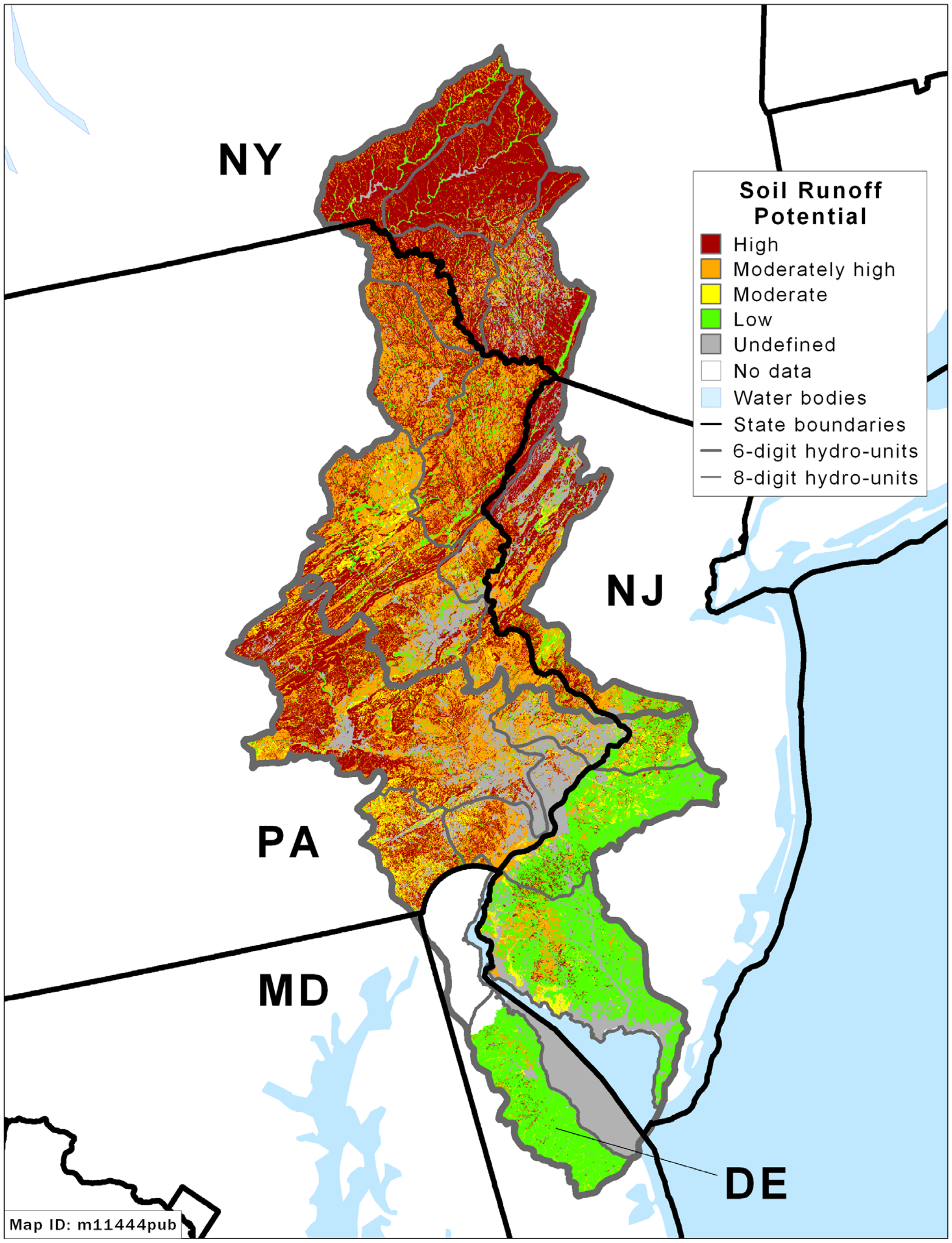
Hydrologic soil groups are classified as:

- **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.

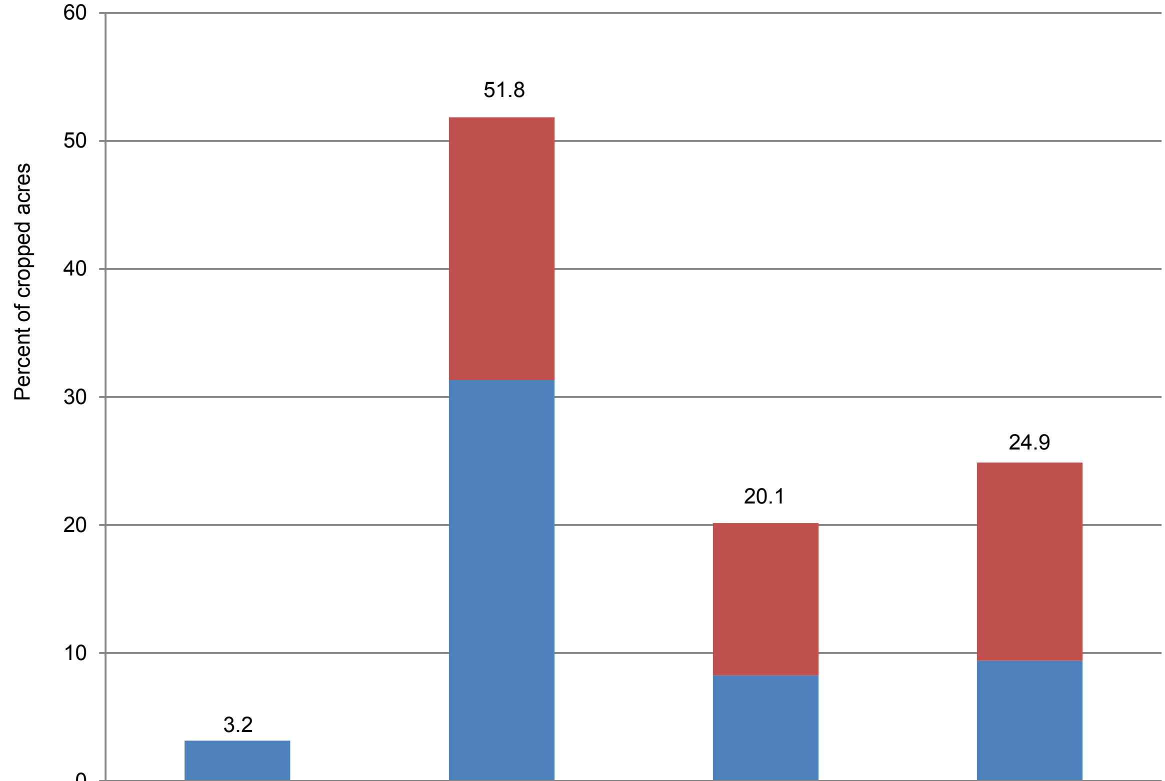
Note: About 48 percent of cropped acres in the Delaware River Basin are highly erodible land (HEL).

Figure 46. Soil runoff potential for soils in the Delaware River Basin



Note: The soil runoff potential shown in this map was derived using the criteria presented in figure 45 applied to soil characteristics for SSURGO polygons. All soils and land uses are represented.

Figure 47. Soil leaching potential for cropped acres in the Delaware River Basin



	Low	Moderate	Moderately high	High
HEL	0.0	20.5	11.9	15.5
Non-HEL	3.2	31.3	8.3	9.4

Criteria for four classes of soil leaching potential were derived using a combination of soil hydrologic group, percent 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

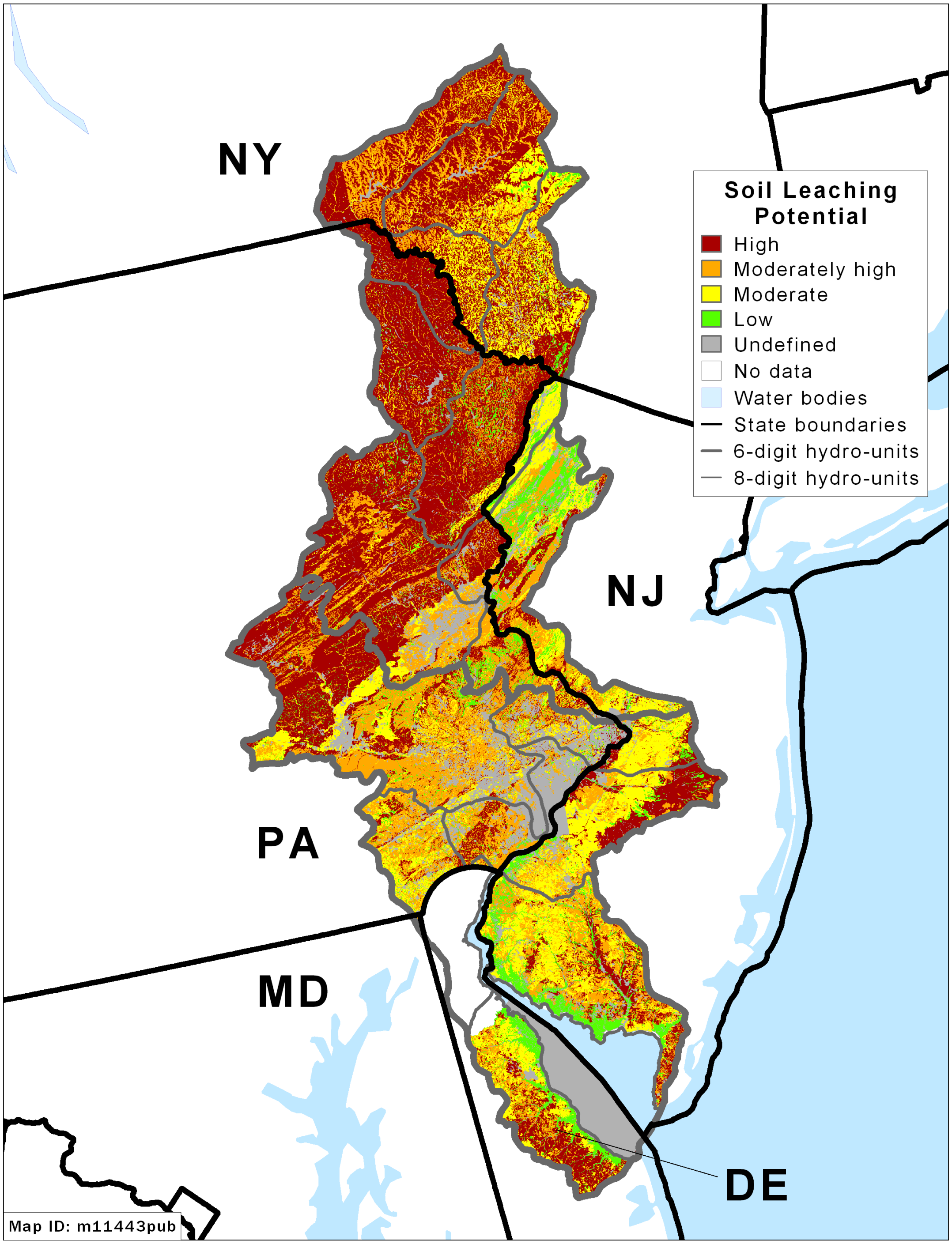
Coarse fragments (stones and rocks) in the soil make it easier for water to infiltrate rather than run off. If the coarse fragment content of the soil was greater than 30 percent, the soil leaching potential was increased two levels (moderate and moderately high to high, and low to moderately high).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

Note: 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 48 percent of cropped acres in the Delaware River Basin are highly erodible land (HEL).

Figure 48. Soil leaching potential for soils in the Delaware River Basin

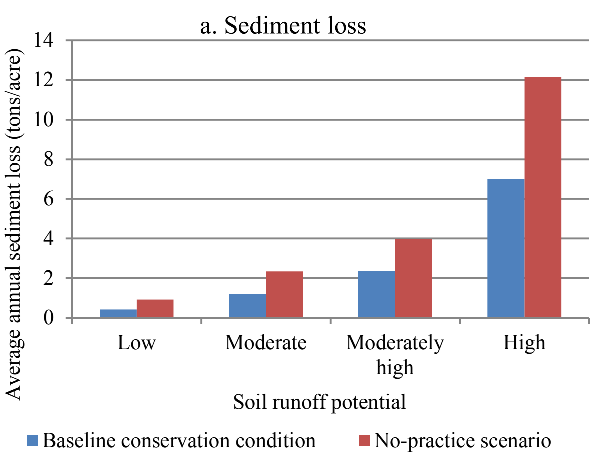


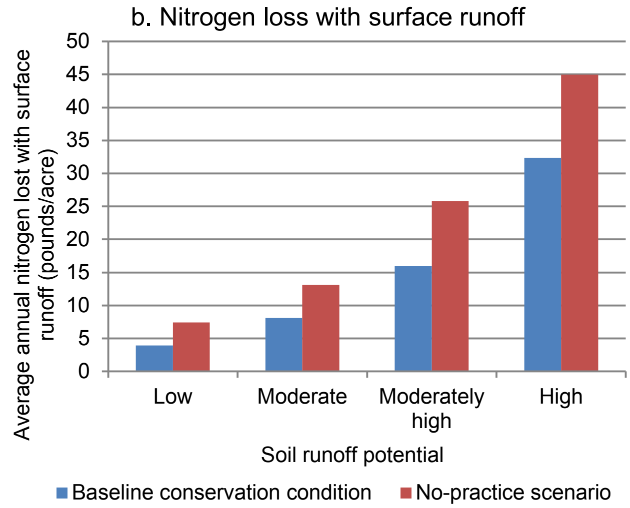
Note: The soil leaching potential shown in this map was derived using the criteria presented in figure 47 applied to soil characteristics for SSURGO polygons. All soils and land uses are represented.

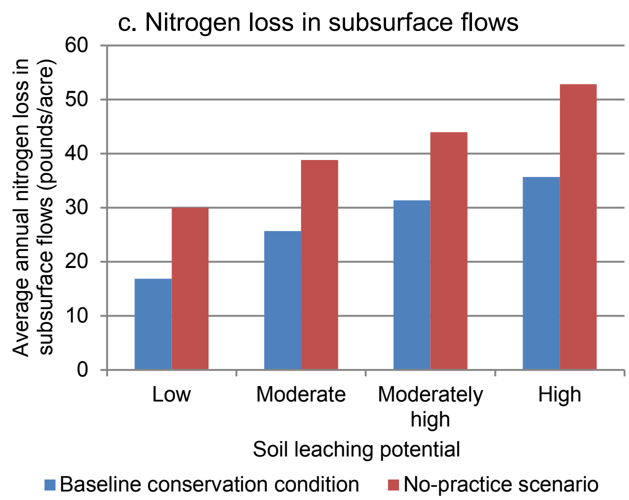
Estimates of sediment and nutrient losses for the no-practice scenario (without conservation practices), presented in figure 49, demonstrate how vulnerability factors influence losses in the Delaware River Basin. Estimates for the baseline are also presented in figure 49 to show how current levels of conservation treatment have reduced losses.

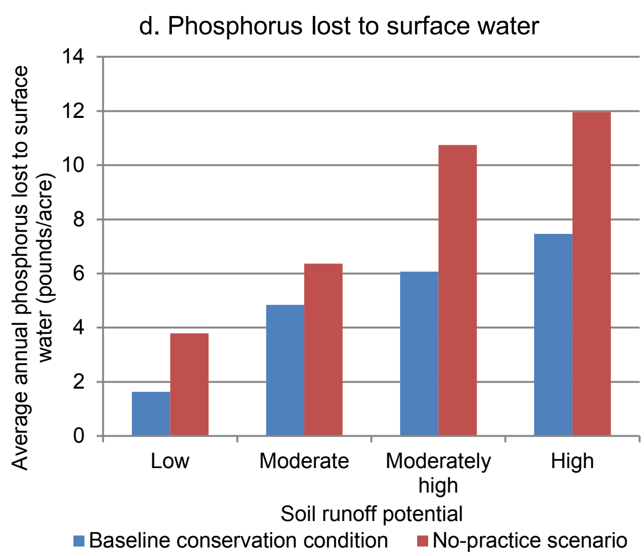
- Sediment loss for the high soil runoff potential would have averaged 12.1 tons per acre per year without conservation practices, compared to 0.9 ton per acre per year for the low soil runoff potential (fig. 49a). The average annual reduction due to conservation practices is 5.1 tons per acre for soils with a high soil runoff potential, compared to a reduction of only 0.5 ton per acre for soils with a low soil runoff potential.
- Nitrogen loss with surface runoff for the high soil runoff potential would have averaged 45 pounds per acre per year without conservation practices, compared to 7 pounds per acre per year for the low soil runoff potential (fig. 49b). The average annual reduction due to conservation practices is 13 pounds per acre for soils with a high soil runoff potential, compared to a reduction of 3 pounds per acre for soils with a low soil runoff potential.
- Nitrogen loss in subsurface flows for the high soil leaching potential would have averaged 53 pounds per acre per year without conservation practices, compared to 30 pounds per acre per year for the low soil leaching potential (fig. 49c). The average annual reduction due to conservation practices is 17 pounds per acre for soils with a high soil leaching potential, compared to a reduction of 13 pounds per acre for soils with a low soil leaching potential.
- Phosphorus lost to surface water for the high soil runoff potential would have averaged 12.0 pounds per acre per year without conservation practices, compared to 3.8 pounds per acre per year for the low soil runoff potential (fig. 49d). The average annual reduction due to conservation practices is 4.5 pounds per acre for soils with a high soil runoff potential, compared to a reduction of 2.2 pounds per acre for soils with a low soil runoff potential.

Figure 49. Average annual sediment and nutrient losses for four levels of vulnerability potentials, Delaware River Basin









Evaluation of Conservation Treatment

The "matrix approach"

A "matrix approach" was used to identify acres where the level of conservation treatment is inadequate relative to the level of inherent vulnerability. These acres are referred to as "undertreated acres." Cropped acres were divided into 16 groups—defined by the four soil vulnerability potentials and four conservation treatment levels. The evaluation of conservation treatment needs was conducted by identifying which of the 16 groups of acres are inadequately treated with respect to the vulnerability potential.

The matrixes are presented for each of the four resource concerns in tables 22 through 25. Each table includes seven sets of matrixes that, taken together, capture the effects of conservation practices in the region and identify the need for additional conservation treatment.

Acres and model results for each of the 16 groupings are presented in the first five matrixes in each table. The combination of the four soil vulnerability potentials and the four conservation treatment levels separates the acres with high losses from the acres with low losses. There generally is a trend of decreasing losses with increasing conservation treatment levels within each vulnerability potential. The tables also demonstrate that the high and moderately high treatment levels are effective in reducing losses at all vulnerability potentials.

The last two matrixes in each table show how conservation treatment needs were identified. Three levels of conservation treatment need were defined.

- **Acres with a "high" level of need** for conservation treatment consist of the most critical undertreated acres in the region. These are the most vulnerable of the undertreated acres with the least conservation treatment and have the highest erosion and/or loss of nutrients.

- **Acres with a "moderate" level of need** for conservation treatment consist of undertreated acres that generally have lower levels of vulnerability 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 soil 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 attained by adding conservation practices to some of these acres, additional conservation treatment would reduce field losses by only a small amount.

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 undertreated 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. These are referred to as "acceptable levels." *Losses above these levels were treated as unacceptable levels of loss.* "Acceptable levels"[25] 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, and
   - 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.

Undertreated 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, undertreated acres consist of acres where the conservation treatment level was one step or more below the soil vulnerability potential.

[25] The long-term average loss was used as the criteria because losses vary considerably from year to year, and the evaluation is intended to assess the adequacy of conservation treatment over all years, on average. Average annual losses derived from APEX model output simulated over 47 years of actual weather (1960 through 2006) were compared to the acceptable level criteria for each sample point.

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 Delaware River Basin, for example, percentages of acres that can attain these acceptable levels with additional soil erosion control and nutrient management practices on all undertreated acres are (see the next chapter)—

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

The criteria used to identify acres that need additional conservation 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 conservation treatment is needed to meet Federal, State, and/or local water quality goals in the region is beyond the scope of this study.

Why Was a Threshold Approach Not Used?

A threshold approach is where all acres with edge-of-field losses above a specific level are identified as undertreated acres; and thus, all acres below that level of loss are considered adequately treated.

A threshold approach is impractical for use in evaluating the adequacy of conservation practice use at the field level. Determination of the threshold level would need to be based on the environmental goals for a watershed, which would be expected to vary from watershed to watershed. Different thresholds would likely be needed for each field, depending on the cropping system. Moreover, sediment and nutrient losses vary from year to year; a specific set of practices shown to reduce losses below a specific level in some years will fail to do so in other years, even among acres that are fully treated. Inexpensive monitoring technologies do not exist for estimating sediment and nutrient losses on a field-by-field basis to determine what level of treatment is needed to meet an edge-of-field loss threshold, further hampering adaptive management efforts by producers.

The conservation goal is full treatment—not treatment to an arbitrary threshold. Protocols for full treatment—avoid, control, and trap—apply equally to all fields in all settings. The hallmark of the matrix approach is that soil vulnerability levels and the existing conservation treatment levels can be readily determined during the conservation planning process. Acres with treatment needs can be readily identified by farmers and conservation planners and treated as needed.

Table 22. Identification of undertreated acres for sediment loss due to water erosion in the Delaware River Basin

Soil runoff potential	Conservation treatment levels for water erosion control				
	Low	Moderate	Moderately high	High	All
Estimated cropped acres					
Low	49,118	219,819	28,221	72,686	369,844
Moderate	33,494	81,183	3,466	4,135	122,278
Moderately high	59,653	58,628	9,902	16,090	144,274
High	82,765	112,504	13,935	0	209,204
All	225,031	472,134	55,524	92,912	845,600
Percent of cropped acres					
Low	6	26	3	9	44
Moderate	4	10	0	0	14
Moderately high	7	7	1	2	17
High	10	13	2	0	25
All	27	56	7	11	100
Sediment loss estimates *without* conservation practices (no-practice scenario, average annual tons/acre)					
Low	1.4	0.9	1.3	0.5	0.9
Moderate	3.1	2.1	2.8	0.6	2.4
Moderately high	4.5	4.2	0.9	3.1	4.0
High	9.5	14.8	6.1	NA	12.1
All	5.4	4.8	2.5	1.0	4.4
Sediment loss estimates for the baseline conservation condition (average annual tons/acre)					
Low	0.9	0.4	0.4	0.2	0.4
Moderate	2.0	0.9	1.3	0.3	1.2
Moderately high	3.4	2.3	0.2	0.1	2.4
High	6.4	8.3	0.3	NA	7.0
All	3.7	2.6	0.4	0.2	2.5
Percent reduction in sediment loss due to conservation practices					
Low	36	57	68	64	55
Moderate	37	56	54	52	49
Moderately high	23	46	83	96	40
High	33	44	95	NA	42
All	31	46	84	81	44
Percent of acres in baseline conservation condition with average annual sediment loss more than 2 tons/acre					
Low	0	4	0	0	2
Moderate	16	8	0	0	10
Moderately high	75	62	0	0	56
High	88	81	0	0	78
All	55	30	0	0	31
Estimate of undertreated acres					
Low	0	0	0	0	0
Moderate	0	0	0	0	0
Moderately high	59,653	58,628	0	0	118,281
High	82,765	112,504	0	0	195,269
All	142,418	171,132	0	0	313,551

Note: Yellow and orange shaded cells indicate undertreated acres; groups of acres with more than 30 percent of the acres exceeding acceptable levels were defined as undertreated acres. Orange-shaded cells indicate critical undertreated acres; critical undertreated 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 23. Identification of undertreated acres for nitrogen loss with surface runoff (sediment attached and soluble) in the Delaware River Basin

Soil runoff potential	Conservation treatment levels for nitrogen runoff control: Low	Moderate	Moderately high	High	All
Estimated cropped acres					
Low	33,813	211,800	116,158	8,072	369,844
Moderate	24,841	84,787	12,650	0	122,278
Moderately high	51,912	76,271	16,090	0	144,274
High	61,563	147,641	0	0	209,204
All	172,130	520,499	144,899	8,072	845,600
Percent of cropped acres					
Low	4	25	14	1	44
Moderate	3	10	1	0	14
Moderately high	6	9	2	0	17
High	7	17	0	0	25
All	20	62	17	1	100
Estimates of nitrogen loss with surface runoff *without* conservation practices (no-practice scenario, average annual pounds/acre)					
Low	8	8	7	NA	7
Moderate	14	13	10	NA	13
Moderately high	27	27	17	NA	26
High	42	46	NA	NA	45
All	27	22	8	NA	21
Estimates of nitrogen loss with surface runoff for the baseline conservation condition (average annual pounds/acre)					
Low	4	4	4	NA	4
Moderate	7	9	5	NA	8
Moderately high	19	16	5	NA	16
High	34	32	NA	NA	32
All	20	14	4	NA	14
Percent reduction in nitrogen loss with surface runoff due to conservation practices					
Low	49	45	51	NA	47
Moderate	47	35	44	NA	38
Moderately high	28	41	71	NA	38
High	19	31	NA	NA	28
All	25	35	55	NA	34
Percent of acres in baseline conservation condition with average annual nitrogen loss with surface runoff more than 15 pounds/acre					
Low	0	0	0	0	0
Moderate	0	8	0	0	5
Moderately high	60	55	0	0	51
High	87	77	0	0	80
All	49	31	0	0	29
Estimate of undertreated acres for nitrogen loss with surface runoff					
Low	0	0	0	0	0
Moderate	0	0	0	0	0
Moderately high	51,912	76,271	0	0	128,183
High	61,563	147,641	0	0	209,204
All	113,475	223,912	0	0	337,387

Note: Yellow and orange-shaded cells indicate undertreated acres; groups of acres with more than 30 percent of the acres exceeding acceptable levels were defined as undertreated acres. Orange-shaded cells indicate critical undertreated acres; critical undertreated 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 or too few acres in the category.

Table 24. Identification of undertreated acres for nitrogen loss in subsurface flows in the Delaware River Basin

Soil leaching potential	Conservation treatment levels for nitrogen management: Low	Moderate	Moderately high	High	All
Estimated cropped acres					
Low	0	7,092	8,388	11,204	26,685
Moderate	88,767	139,169	123,060	87,303	438,300
Moderately high	20,477	78,560	65,297	5,978	170,312
High	45,216	69,518	88,074	7,496	210,303
All	154,460	294,339	284,819	111,981	845,600
Percent of cropped acres					
Low	0	1	1	1	3
Moderate	10	16	15	10	52
Moderately high	2	9	8	1	20
High	5	8	10	1	25
All	18	35	34	13	100
Estimates of nitrogen loss in subsurface flows *without* conservation practices (no-practice scenario, average annual pounds/acre)					
Low	NA	53	21	22	30
Moderate	64	43	29	20	39
Moderately high	59	50	32	NA	44
High	60	61	45	NA	53
All	62	50	34	22	43
Estimates of nitrogen loss in subsurface flows for the baseline conservation condition (average annual pounds/acre)					
Low	NA	36	11	9	17
Moderate	51	34	11	8	26
Moderately high	46	47	10	NA	31
High	53	47	20	NA	36
All	51	40	13	9	29
Percent reduction in nitrogen loss in subsurface flows due to conservation practices					
Low	NA	32	47	59	44
Moderate	19	23	62	62	34
Moderately high	21	6	70	NA	29
High	12	23	56	NA	32
All	18	19	61	60	33
Percent of acres in baseline conservation condition with average annual nitrogen loss in subsurface flows more than 25 pounds/acre					
Low	0	30	0	0	8
Moderate	37	56	2	0	26
Moderately high	49	55	4	0	33
High	100	87	21	0	59
All	57	62	8	0	35
Estimate of undertreated acres for nitrogen loss in subsurface flows					
Low	0	7,092	0	0	7,092
Moderate	88,767	139,169	0	0	227,937
Moderately high	20,477	78,560	0	0	99,036
High	45,216	69,518	0	0	114,734
All	154,460	294,339	0	0	448,799

Note: Yellow and orange-shaded cells indicate undertreated acres; groups of acres with more than 30 percent of the acres exceeding acceptable levels were defined as undertreated acres. Orange-shaded cells indicate critical undertreated acres; critical undertreated 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 or too few acres in the category.

Table 25. Identification of undertreated acres for phosphorus lost to surface water (phosphorus attached to sediment and in solution, including soluble phosphorus in subsurface lateral flow pathways) in the Delaware River Basin

Soil runoff potential	Conservation treatment levels for phosphorus runoff control: Low	Moderate	Moderately high	High	All
Estimated cropped acres					
Low	67,362	137,264	141,839	23,379	369,844
Moderate	76,650	30,601	15,027	0	122,278
Moderately high	44,828	73,454	23,906	2,087	144,274
High	84,617	106,175	18,413	0	209,204
All	273,456	347,494	199,185	25,465	845,600
Percent of cropped acres					
Low	8	16	17	3	44
Moderate	9	4	2	0	14
Moderately high	5	9	3	<1	17
High	10	13	2	0	25
All	32	41	24	3	100
Phosphorus lost to surface water *without* conservation practices (no-practice scenario, average annual pounds/acre)					
Low	2.7	4.1	3.9	4.3	3.8
Moderate	7.4	4.3	5.1	NA	6.4
Moderately high	13.3	10.5	6.9	NA	10.7
High	14.2	10.3	11.5	NA	12.0
All	9.3	7.4	5.1	4.7	7.4
Phosphorus lost to surface water for the baseline conservation condition (average annual pounds/acre)					
Low	2.6	2.3	0.7	0.7	1.6
Moderate	6.8	1.5	1.6	NA	4.8
Moderately high	11.4	4.3	1.7	NA	6.1
High	11.5	5.2	2.1	NA	7.5
All	8.0	3.5	1.0	0.7	4.3
Percent reduction in phosphorus lost to surface water due to conservation practices					
Low	3	44	83	85	57
Moderate	8	66	68	NA	24
Moderately high	14	58	75	NA	44
High	19	50	82	NA	38
All	14	52	80	85	42
Percent of acres in baseline conservation condition with average annual phosphorus lost to surface water more than 4 pounds/acre					
Low	25	18	0	0	11
Moderate	75	0	0	0	47
Moderately high	81	18	16	0	37
High	82	85	0	0	76
All	66	37	2	0	37
Estimate of undertreated acres for phosphorus lost to surface water					
Low	0	0	0	0	0
Moderate	76,650	0	0	0	76,650
Moderately high	44,828	0	0	0	44,828
High	84,617	106,175	0	0	190,791
All	206,094	106,175	0	0	312,268

Note: Yellow and orange-shaded cells indicate undertreated acres; groups of acres with more than 30 percent of the acres exceeding acceptable levels were defined as undertreated acres. Orange-shaded cells indicate critical undertreated acres; critical undertreated 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 or too few acres in the category.

Conservation treatment needs by resource concern

Most of the cropped acres in the Delaware River Basin were determined to be undertreated and in need of additional conservation treatment. The proportion of cropped acres with a high or moderate need for additional conservation treatment was determined to be (fig. 50 and table 26)—

- 37 percent for sediment loss (all with a high need for treatment),
- 40 percent for nitrogen loss with runoff (31 percent with a high need for treatment),
- 37 percent for phosphorus lost to surface water (all with a high need for treatment), and
- 53 percent for nitrogen loss in subsurface flows (14 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.

A total of 623,486 cropped acres in this region need additional conservation treatment—74 percent (table 26). Most of the undertreated acres need additional treatment for multiple resource concerns.

Undertreated acres in the Delaware River Basin are presented by combinations of resource concerns in table 26. One third of the undertreated acres need additional treatment for nitrogen leaching only. Twenty-eight percent of undertreated acres need additional treatment for sediment loss and/or nitrogen or phosphorus loss with surface water runoff but do not need additional treatment for nitrogen leaching. About one-fourth of the undertreated acres need treatment for all four resource concerns.

Both erosion control and nutrient management are critical conservation concerns in this region.

Figure 50. Percent of cropped acres that are undertreated in the Delaware River Basin, by resource concern

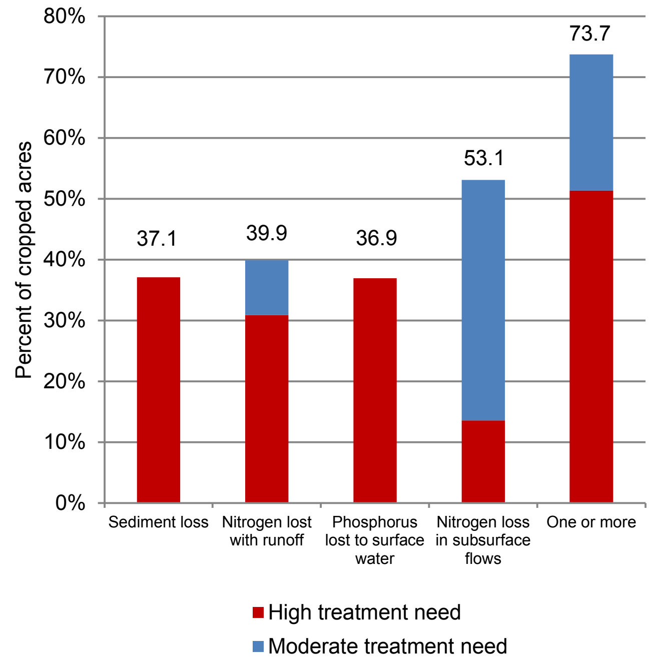


Table 26. Undertreated acres with resource concerns needing treatment in the Delaware River Basin

Reason for treatment need		Estimated acres needing treatment	Percent of cropped acres	Percent of undertreated acres
Nitrogen leaching only		209,451	24.8	33.6
Sediment, nitrogen runoff, nitrogen leaching, and phosphorus runoff		149,216	17.6	23.9
Sediment, nitrogen runoff, phosphorus runoff		78,767	9.3	12.6
Sediment and nitrogen runoff		60,465	7.2	9.7
Phosphorus runoff and nitrogen leaching		41,194	4.9	6.6
Phosphorus runoff only		35,455	4.2	5.7
Sediment, nitrogen runoff, nitrogen leaching		25,102	3.0	4.0
Nitrogen leaching and nitrogen runoff		16,201	1.9	2.6
Nitrogen runoff, nitrogen leaching, and phosphorus runoff		7,635	0.9	1.2
	All undertreated acres	623,486	73.7	100.0

Note: This table summarizes the undertreated acres identified in tables 22-25 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 conservation treatment needs for the Delaware River Basin determined the following (fig. 51):

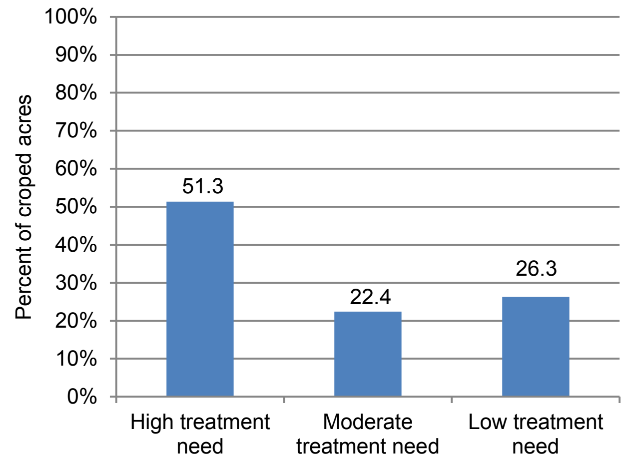
- 51.3 percent of cropped acres (434,212 acres) have a **high** level of need for additional conservation treatment,
- 22.4 percent of cropped acres (189,276 acres) have a **moderate** level of need for additional conservation treatment, and
- 26.3 percent of cropped acres (222,113 acres) have a **low** level of need for additional treatment and are considered to be adequately treated.

High level of need for conservation treatment. These are the most vulnerable of the undertreated acres with the least conservation treatment and have the highest losses of sediment and/or nutrients. In the Delaware River Basin, these 434,212 acres lose (per acre per year, on average) 4.4 tons of sediment by water erosion, 7.0 pounds of phosphorus, and 62 pounds of nitrogen (table 27).

Moderate level of need for conservation treatment. Acres with a "moderate" level of need for conservation treatment consist of undertreated acres that generally have lower levels of vulnerability and/or have more conservation practice use than do acres with a high level of need. In the Delaware River Basin, these 189,276 acres lose (per acre per year, on average) 0.4 ton of sediment by water erosion, 2.0 pounds of phosphorus, and 52 pounds of nitrogen (table 27).

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. In the Delaware River Basin, these 222,113 acres lose (per acre per year, on average) 0.4 ton of sediment by water erosion, 1.5 pounds of phosphorus, and 18 pounds of nitrogen (table 27). While gains can be attained by adding conservation practices to some of these acres with a low treatment need, additional conservation treatment would reduce average field losses by only a small amount.

Figure 51. 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 Delaware River Basin



What is "Adequate Conservation Treatment?"

A field with adequate conservation practice use will have combinations of practices that address all the specific inherent vulnerability factors that determine the potential for sediment, nutrient, and pesticide losses. Full treatment consists of a suite of practices that—

- avoid or limit the potential for contaminant losses 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.

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. Acres with characteristics such as steeper slopes and soil types that promote surface water runoff are more vulnerable to sediment, nutrient, and pesticide losses beyond the edge of the field. Acres that are essentially flat with permeable soil types are more prone to soluble nutrient and pesticide losses through subsurface flow pathways, most of which return to surface water through drainage ditches, tile drains, natural seeps, and groundwater return flow.

In practice, a *comprehensive planning process* is used to identify the appropriate combination of nutrient management techniques, soil erosion control practices, and other conservation practices needed to address the specific inherent vulnerabilities associated with each field.

In this report, adequate conservation treatment is limited to the use of practices that will not require changes in the cropping systems or changes in regional crop production levels. It may be necessary in some environmental settings to go beyond "adequate conservation treatment" to achieve local environmental goals.

Table 27. Baseline conservation condition model simulation results for subsets of undertreated and adequately treated acres in the Delaware River Basin

Model simulated outcome, average annual values	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	222,113	189,276	434,212	845,600
Percent of acres	26.3%	22.4%	51.3%	100.0%
Water flow				
Surface runoff (inches)	6.3	5.9	8.1	7.1
Subsurface water flow (inches)	12.0	12.9	11.4	11.9
Erosion and sediment loss				
Wind erosion (tons/acre)	0.05	0.05	0.04	0.04
Sheet and rill erosion (tons/acre)	0.49	0.56	2.81	1.70
Sediment loss at edge of field due to water erosion (tons/acre)	0.43	0.42	4.45	2.49
Soil organic carbon				
Change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)	-61	-5	-167	-103
Nitrogen				
Nitrogen sources (pounds/acre)				
Atmospheric deposition	7.7	7.7	9.5	8.6
Bio-fixation by legumes	46.2	27.4	24.0	30.6
Nitrogen applied as commercial fertilizer and manure	44.6	106.4	87.2	80.3
All nitrogen sources	98.5	141.5	120.7	119.5
Nitrogen in crop yield removed at harvest (pounds/acre)	87.3	90.8	75.2	81.9
Nitrogen loss				
Loss of nitrogen through volatilization (pounds/acre)	2.9	6.4	4.7	4.6
Nitrogen returned to the atmosphere through denitrification (pounds/acre)	0.3	0.8	1.5	1.0
Loss of nitrogen with windborne sediment (pounds/acre)	0.3	0.3	0.1	0.2
Loss of nitrogen with surface runoff, including waterborne sediment (pounds/acre)	3.9	4.5	22.6	13.6
Nitrogen loss in subsurface flows (pounds/acre)	10.8	40.1	33.5	29.0
Total nitrogen loss for all pathways (pounds/acre)	18.1	52.1	62.5	48.5
Phosphorus				
Phosphorus applied (pounds/acre)	14.7	19.8	24.5	20.9
Phosphorus in crop yield removed at harvest (pounds/acre)	13.3	14.0	11.9	12.7
Phosphorus loss				
Loss of phosphorus with windborne sediment (pounds/acre)	0.05	0.05	0.05	0.05
Loss of phosphorus to surface water, including both soluble and sediment attached (pounds/acre)*	1.39	1.94	6.81	4.29
Total phosphorus loss for all pathways (pounds/acre)	1.51	2.04	6.96	4.43
Pesticide loss				
Mass loss of pesticides for all pathways (grams of active ingredient/hectare)	6.0	10.9	22.7	15.7
Surface water pesticide risk indicator for aquatic ecosystem	1.5	1.5	2.4	2.0
Surface water pesticide risk indicator for humans	0.2	0.3	0.5	0.4

* Includes phosphorus lost with waterborne sediment and soluble phosphorus in subsurface flows that are intercepted by tile drains and drainage ditches, lateral subsurface outflow (seeps), and groundwater return flow.

Conservation treatment needs by cropping systems

Five of the eight cropping systems in this region have a disproportionately high percentage of acres that need additional treatment, shown in table 28, although they are only weakly disproportionate. Three of the eight cropping systems have a disproportionately low percentage of undertreated acres. The most striking example is the "soybean only" cropping system, which makes up 8 percent of the cropped acres in the basin but accounts for only 1 percent of the undertreated acres in the basin. Only 6 percent of the cropped acres in the "soybean only" cropping system are undertreated, compared to 74 percent for all cropped acres.

Assessment of only the critical undertreated acres (those acres with a high need for additional treatment) shows that disproportionality is more pronounced (table 29). Three cropping systems have a disproportionately high percentage of critical undertreated acres—corn with close grown crops, hay-crop mixes, and corn and soybean only. These three cropping systems make up 47 percent of cropped acres but account for 66 percent of the critical undertreated acres in the region. About 73 percent of the cropped acres in these three cropping systems are critically undertreated, compared to 51 percent for all cropped acres.

Table 28. Percent of undertreated acres (acres with a *high* or *moderate* level of treatment need) by cropping system, Delaware River Basin

Cropping system	Percent of cropped acres in Delaware River Basin	Percent of undertreated acres in Delaware River Basin	Percent of undertreated acres in cropping system
Disproportionately high percentage of undertreated acres			
Corn with close grown crops	8	11	100
Tobacco or vegetables with or without other crops	6	7	87
Hay-crop mix	12	13	84
Corn and soybean only	27	30	83
Corn and soybean with close grown crops	19	21	83
Disproportionately low percentage of undertreated acres			
Soybean only	8	1	6
Remaining crop mixes	6	4	43
Corn only	14	12	64
Total	100	100	74

Note: Percents may not add to totals because of rounding.
* Percent of undertreated acres in the region.

Table 29. Percent of critical undertreated acres (acres with a *high* level of treatment need) by cropping system, Delaware River Basin

Cropping system	Percent of cropped acres in Delaware River Basin	Percent of critical undertreated acres in Delaware River Basin	Percent of critical undertreated acres in cropping system
Disproportionately high percentage of critical undertreated acres			
Corn with close grown crops	8	16	100
Hay-crop mix	12	18	79
Corn and soybean only	27	32	62
Disproportionately low percentage of critical undertreated acres			
Soybean only	8	1	6
Remaining crop mixes	6	2	14
Tobacco or vegetables with or without other crops	6	3	26
Corn only	14	11	41
Corn and soybean with close grown crops	19	16	45
Total	100	100	51*

Note: Percents may not add to totals because of rounding.
* Percent of critical undertreated acres in the region.

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

Model simulations were used to evaluate the potential gains from further conservation treatment in the Delaware River Basin. The simulated treatment levels were designed to minimally affect crop yields and maintain regional production capacity for food, fiber, forage, and fuel. 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.

Three sets of additional conservation practices were simulated:

1. Additional water erosion control practices consisting of three types of structural practices—overland flow practices, concentrated flow practices, and edge-of-field mitigation.
2. Application of nitrogen and phosphorus using appropriate rate, timing, and method.
3. Increases in the efficiency of irrigation water application.

Four conservation treatment scenarios were simulated to evaluate the potential gains from further conservation treatment:

1. Treatment of the 434,212 critical undertreated acres (acres with a high need for conservation treatment) with water erosion control practices only.
2. Treatment of all 623,486 undertreated acres (acres with a high or moderate need for conservation treatment) with water erosion control practices only.
3. Treatment of the 434,212 critical undertreated acres with nutrient management practices in addition to water erosion control practices to address nutrient losses.
4. Treatment of all 623,486 undertreated acres with nutrient management practices in addition to water erosion control practices to address nutrient losses.

In summary, the potential for achieving additional field-level savings from further conservation treatment is high in this region. Conservation practices in use in 2003–06 achieved 46 percent of potential reductions in sediment loss, 47 percent for nitrogen, and 52 percent for phosphorus. By treating all 623,486 undertreated acres in the region with additional erosion control and nutrient management practices, an additional 52 percent in savings would be attained for sediment, 52 percent for nitrogen, and 44 percent for phosphorus. The bulk of these savings would be achieved by treating the critical undertreated acres. To achieve 100 percent of potential savings (i.e., an additional 2 percent for sediment,1 percent for nitrogen, and 3 percent for phosphorus), additional conservation treatment for the remaining 222,113 acres with a low need for additional treatment would be required, which would result in very small conservation gains on a per-acre basis.

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.

In the derivation of conservation plans, other conservation practices would be considered, such as cover crops, tillage and residue management, conservation crop rotations, drainage water management, and emerging conservation technologies. Only erosion control structural practices and consistent nutrient management techniques were simulated here to serve as a proxy for the more comprehensive suite of practices that is obtained through the conservation planning process. For example, a conservation plan may include tillage and residue management and cover crops instead of some of the structural practices included in the model simulation. Similarly, drainage water management or cover crops might be used as a substitute for—or in addition to—strict adherence to the right rate, timing, and method of nutrient application.

Pesticide management was also not addressed directly in the treatment scenarios. While erosion control practices influence pesticide transport and loss, significant reductions in pesticide edge-of-field environmental 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.

The level of conservation treatment is simulated to show *potential* environmental benefits, but is not designed to achieve specific environmental protection goals.

Nor were treatment scenarios designed to represent actual program or policy options for the Delaware River Basin. Economic and programmatic aspects—such as producer costs, conservation program costs, and capacity to deliver the required technical assistance—were not considered in the assessment of the potential gains from further conservation treatment.

Simulation of Additional Water Erosion Control Practices

Treatment to control water erosion and surface water runoff consists of structural and vegetative practices that slow runoff water and capture contaminants that it may carry. Simulations of practices were added where needed (summarized in table 30) 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.

Table 30. Summary of additional structural practices for water erosion control simulated for undertreated acres to assess the potential for gains from additional conservation treatment in the Delaware River Basin

	Critical undertreated acres (acres with a high level of treatment need)		Non-critical undertreated acres (acres with a moderate level of treatment need)		All undertreated acres	
Additional practice	Treated acres	Percent of total	Treated acres	Percent of total	Treated acres	Percent of total
Overland flow practice only	0	0	0	0	0	0
Terrace only	7,687	2	3,898	2	11,585	2
Terrace plus overland flow practice	0	0	0	0	0	0
Filter only	56,917	13	112,552	59	169,469	27
Filter plus overland flow practice	28,893	7	14,783	8	43,677	7
Filter plus terrace	269,914	62	2,894	2	272,808	44
Filter plus overland flow practice plus terrace	0	0	0	0	0	0
Buffer only	12,817	3	40,048	21	52,865	8
Buffer plus overland flow practice	8,528	2	1,924	1	10,452	2
Buffer plus terrace	49,456	11	0	0	49,456	8
Buffer plus overland flow practice plus terrace	0	0	0	0	0	0
One or more additional practices	434,212	100	176,099	93	610,311	98
No structural practices	0	0	13,177	7	13,177	2
Total	434,212	100	189,276	100	623,487	100

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

Simulation of Additional Nutrient Management Practices

The nutrient management treatment scenario consists of additional nutrient management practices where needed *in addition to* the 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 of application 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 11 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.

In the baseline condition, about 10 percent of the cropped acres in the Delaware River Basin 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.

Specific rules for method of application

If the method of application was other than incorporation then in the simulations fertilizer and manure applications became incorporated or injected. Incorporation reduces the opportunity for nutrients on the soil surface to volatize or be carried away in 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 ammonium or nitrate ratio of the fertilizer.

Specific rules for the rate of nutrient applied

Nitrogen application rates above 1.2 times the crop removal rate were reduced in the simulations to 1.2 times the crop removal rate for all crops except small grain crops. The 1.2 ratio is in the range of rates recommended by many of the land grant universities. This rate accounts for the savings in nutrients due to improved application timing and implementation of water erosion control practices and also replaces a reduced amount of environmental losses that occur during the cropping season.

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

Phosphorus application rates above 1.1 times the amount of phosphorus removed in the crop at harvest over the crop rotation were adjusted to be equal to 1.1 times the amount of phosphorus removed in the crop at harvest over the crop rotation. Application rates for all phosphorus applications in the rotation were reduced in equal proportions.

Simulation of Irrigation Water Use Efficiency

Increases in the efficiency of irrigation water conveyances and water application were simulated in both the erosion control scenario and the erosion control with nutrient management treatment scenario. The volume of irrigation water used was simulated in the same manner as described for the baseline scenario in chapter 4. (Irrigation water was applied in the APEX model when a yield stress exceeded a specified threshold; the amount of irrigation water applied was determined by the amount of irrigation water required to fill the root-zone after accounting for conveyance losses.)

Implementation of the treatment scenario on all irrigated acres would result in an additional 70.000 acres converted to center pivot or linear move sprinkler systems with low pressure heads.

In the Delaware River Basin, the representation of irrigation management in the treatment scenarios increased the average Virtual Irrigation System Efficiency (VISE) from 67 percent in the baseline conservation condition to 80 percent in the treatment scenarios. (As discussed in chapter 3, irrigation efficiencies were represented in APEX simulations as a combination of three different coefficients [losses at the head of the field, percolation losses, and end-of-field runoff] combined into a single efficiency value, VISE).

Emerging Technologies for Reducing Nutrient Losses from Farm Fields

The nutrient management simulated to assess the potential for further gains from conservation treatment represents traditional nutrient management techniques that have been in use for several years and would be expected to be found in current NRCS conservation plans. There are, however, emerging conservation technologies that have the potential to further reduce nutrient loss from farm fields and provide even greater crop use efficiencies once the technologies become more widespread. These include—

- innovations in implement design to enhance precise nutrient application and placement, including variable rate technologies;
- enhanced-efficiency nutrient application products such as slow or controlled release fertilizers (for example, polymer coated products, sulfur-coated products, etc.) and nitrogen stabilizers (for example, urease inhibitors, and nitrification inhibitors);
- drainage water management that controls discharge of drainage water and provides treatment of contaminants, thereby reducing the levels of nitrogen and even some soluble phosphorus loss;
- constructed wetlands receiving surface water runoff or drainage water from farm fields prior to discharge to streams and rivers; and
- use of riparian corridors for treating drainage water.

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.

Potential for Field-Level Gains

Treatment of the 434,212 critical undertreated acres

Average annual model output is presented in table 31 for the 434,212 critical undertreated acres (acres with a high level of treatment need). The baseline results for these acres are contrasted to model output for the two treatment simulations in that table. According to the model simulation, treatment of these acres with water erosion control practices would substantially reduce sediment loss from water erosion and nitrogen and phosphorus losses with surface water runoff. Sediment loss would be reduced to an annual average of about 0.3 ton per acre per year for these acres, a 93-percent reduction. Nitrogen loss with surface runoff would be reduced to 6.4 pounds per acre per year on average (72-percent reduction), and phosphorus lost to surface water would be reduced to 3.3 pounds per acre per year (52-percent reduction). However, the re-routing of surface water to subsurface flow pathways would *increase* nitrogen loss in subsurface flows by 1 percent for these acres, on average.

The addition of nutrient management would have little additional effect on sediment loss and loss of nitrogen with surface runoff, but would be effective in reducing nitrogen loss in subsurface flows and further reducing phosphorus lost to surface water (table 31). Nitrogen loss in subsurface flows for these acres would be reduced to an average of 20.2 pounds per acre per year, representing a 40-percent reduction compared to losses simulated for the baseline conservation condition. Phosphorus lost to surface water would be reduced to an average of 1.9 pounds per acre per year for these acres, representing a 72-percent reduction compared to the baseline condition.

These results support the conclusion drawn from the assessment of the effects of conservation practices in chapter 4 that nutrient management practices need to be paired with erosion control practices to attain significant reductions in the loss of soluble nutrients from cropped fields.

Treatment of all 623,487 undertreated acres

Average annual model output is presented in table 32 for the treatment of <u>all</u> 623,487 undertreated acres (acres with a high or moderate level of treatment need). The 623,487 undertreated acres include 189,276 acres with a moderate need for treatment that are less vulnerable or have more conservation practice use than the critical undertreated acres, and therefore the potential for gains with additional treatment is less for those acres. Table 32 shows that per-acre percent reductions of sediment and nutrient loss due to additional practices would be less, on average, than percent reductions for treatment of the 434,212 most vulnerable undertreated acres alone.

Nonetheless, the per-acre gains from additional treatment of these acres would be substantial. Treatment with both erosion control and nutrient management would, compared to the baseline results for these 623,487 acres—

- reduce average annual sediment loss from 3.23 tons per acre for the baseline to 0.24 ton per acre (a 93-percent reduction),
- reduce average annual nitrogen loss with surface runoff (including waterborne sediment) from 17.1 pounds per acre to 4.6 pounds per acre (a 73-percent reduction),
- reduce average annual nitrogen loss in subsurface flows from 35.5 pounds per acre to 19.4 pounds per acre (a 45-percent reduction),
- reduce total nitrogen loss (all loss pathways) from 59.3 pounds per acre per year to 28.5 pounds per acre per year (a 52-percent reduction), and
- reduce average annual phosphorus lost to surface water from 5.3 pounds per acre to 1.7 pounds per acre for these acres (a 68-percent reduction).

Diminishing returns from additional conservation treatment

Per-acre gains from additional conservation treatment are highest for the more vulnerable and less treated acres than for the less vulnerable and more treated acres. These “diminishing returns” to additional treatment indicate that targeting treatment to the acres with the greatest need is an efficient way to reduce agricultural sources of contaminants from farm fields within the basin.

Table 33 contrasts the per-acre model simulation results for additional erosion control and nutrient management on three subsets of acres in the Delaware River Basin:

1. the 434,212 undertreated acres with a “high” need for additional treatment,
2. the 189,276 undertreated acres with a “moderate” need for additional treatment, and
3. the 222,113 acres with a “low” need for additional treatment.

Diminishing returns from additional conservation treatment is demonstrated by comparing the average annual per-acre reductions in losses among the three groups of acres.

For example, conservation treatment of the 434,212 critical undertreated acres would reduce sediment loss an average of 4.14 tons per acre per year on those acres. In comparison, additional treatment of the remaining acres would reduce sediment loss by about 0.34 ton per acre per year on the 189,276 undertreated acres with a moderate need for additional treatment and by 0.35 ton per acre per year on the 222,113 acres with a low need for additional treatment (table 33).

Table 31. Conservation practice effects for additional treatment of 434,212 critical undertreated acres (acres with a *high* need for conservation treatment) in the Delaware River Basin

Model simulated outcome	Baseline conservation condition	Treatment with erosion control practices		Treatment with erosion control and nutrient management practices	
	Average annual amount	Average annual amount	Percent reduction	Average annual amount	Percent reduction
Water flow					
Surface water runoff (inches)	8.1	7.0	13%	7.0	13%
Subsurface water flow (inches)	11.4	12.4	-8%	12.3	-8%
Erosion and sediment loss					
Wind erosion (tons/acre)	0.04	0.03	13%	0.03	12%
Sheet and rill erosion (tons/acre)	2.81	0.92	67%	0.94	66%
Sediment loss at edge of field due to water erosion (tons/acre)	4.45	0.30	93%	0.31	93%
Soil organic carbon					
Change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)	-167	-63	62%	-79	53%
Nitrogen					
Nitrogen sources					
Atmospheric deposition	9	9	0%	9	0%
Bio-fixation by legumes	24	23	4%	24	0%
Nitrogen applied (pounds/acre)	87	85*	3%	62	29%
All nitrogen sources	121	117	3%	95	21%
Nitrogen in crop yield removed at harvest (pounds/acre)	75	74	1%	70	6%
Total nitrogen loss for all loss pathways (pounds/acre)	62.5	46.6	25%	30.2	52%
Loss of nitrogen with surface runoff, including waterborne sediment (pounds/acre)	22.6	6.4	72%	5.7	75%
Nitrogen loss in subsurface flows (pounds/acre)	33.5	34.0	-1%	20.2	40%
Phosphorus					
Phosphorus applied (pounds/acre)	24.5	24.3*	1%	17.0	31%
Phosphorus in crop yield removed at harvest (pounds/acre)	11.9	11.7	1%	11.2	6%
Total phosphorus loss for all loss pathways (pounds/acre)	7.0	3.4	51%	2.1	70%
Loss of phosphorus to surface water, including waterborne sediment (pounds/acre)	6.8	3.3	52%	1.9	72%
Pesticide loss					
Mass loss of pesticides for all pathways (grams of active ingredient/hectare)	23	11	51%	11	50%
Surface water pesticide risk indicator for aquatic ecosystems	2.40	1.93	20%	1.93	20%
Surface water pesticide risk indicator for humans	0.49	0.39	20%	0.39	20%

* Total nitrogen and phosphorus applied were slightly 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 434,212 critical undertreated 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 32. Conservation practice effects for additional treatment of 623,487 undertreated acres (acres with a *high* or *moderate* need for conservation treatment) in the Delaware River Basin

Model simulated outcome	Baseline conservation condition	Treatment with erosion control practices		Treatment with erosion control and nutrient management practices	
	Average annual amount	Average annual amount	Percent reduction	Average annual amount	Percent reduction
Water flow					
Surface water runoff (inches)	7.4	6.5	12%	6.5	12%
Subsurface water flow (inches)	11.9	12.7	-7%	12.7	-7%
Erosion and sediment loss					
Wind erosion (tons/acre)	0.04	0.04	9%	0.04	9%
Sheet and rill erosion (tons/acre)	2.13	0.73	66%	0.75	65%
Sediment loss at edge of field due to water erosion (tons/acre)	3.23	0.24	93%	0.24	93%
Soil organic carbon					
Change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)	-118	-43	64%	-56	53%
Nitrogen					
Nitrogen sources					
Atmospheric deposition	9	9	0%	9	0%
Bio-fixation by legumes	25	24	3%	26	-2%
Nitrogen applied (pounds/acre)	93	90*	3%	64	31%
All nitrogen sources	127	123	3%	99	22%
Nitrogen in crop yield removed at harvest (pounds/acre)	80	79	2%	74	7%
Total nitrogen loss for all loss pathways (pounds/acre)	59.3	47.3	20%	28.5	52%
Loss of nitrogen with surface runoff, including waterborne sediment (pounds/acre)	17.1	5.3	69%	4.6	73%
Nitrogen loss in subsurface flows (pounds/acre)	35.5	35.4	<1%	19.4	45%
Phosphorus					
Phosphorus applied (pounds/acre)	23.1	22.9*	1%	17.2	26%
Phosphorus in crop yield removed at harvest (pounds/acre)	12.5	12.3	2%	11.7	6%
Total phosphorus loss for all loss pathways (pounds/acre)	5.5	2.9	47%	1.9	66%
Loss of phosphorus to surface water, including waterborne sediment (pounds/acre)	5.3	2.7	49%	1.7	68%
Pesticide loss					
Mass loss of pesticides for all pathways (grams of active ingredient/hectare)	19	10	45%	11	45%
Surface water pesticide risk indicator for aquatic ecosystems	2.13	1.75	18%	1.75	18%
Surface water pesticide risk indicator for humans	0.44	0.36	17%	0.37	17%

* Total nitrogen and phosphorus applied were slightly 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 623,487 undertreated 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. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices for three groups of acres comprising the 845,600 cropped acres in the Delaware River Basin

	Additional treatment for 434,212 critical undertreated acres*			Additional treatment 189,276 non-critical undertreated acres*			Additional treatment for remaining 222,113 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)	8.1	7.0	1.0	5.9	5.3	0.6	6.3	5.6	0.7
Subsurface water flow (inches)	11.4	12.3	-0.9	12.9	13.5	-0.6	12.0	12.5	-0.6
Erosion and sediment loss									
Wind erosion (tons/acre)	0.04	0.03	0.00	0.05	0.05	0.00	0.05	0.05	0.00
Sheet and rill erosion (tons/acre)	2.81	0.94	1.86	0.56	0.29	0.27	0.49	0.22	0.27
Sediment loss at edge of field due to water erosion (tons/acre)	4.45	0.31	4.14	0.42	0.08	0.34	0.43	0.08	0.35
Soil organic carbon									
Change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)	-167	-79	88**	-5	-4	1**	-61	-54	7**
Nitrogen									
Nitrogen sources									
Atmospheric deposition	9	9	0	8	8	0	8	8	0
Bio-fixation by legumes	24	24	0	27	29	-2	46	45	1
Nitrogen applied (pounds/acre)	87	62	25	106	69	38	45	43	2
All nitrogen sources	121	95	25	141	106	35	98	95	3
Nitrogen in crop yield removed at harvest (pounds/acre)	75	70	5	91	83	8	87	85	3
Total nitrogen loss for all loss pathways (pounds/acre)	62	30	32	52	25	27	18	16	2
Loss of nitrogen with surface runoff, including waterborne sediment (pounds/acre)	23	6	17	4	2	2	4	2	2
Nitrogen loss in subsurface flows (pounds/acre)	34	20	13	40	18	22	11	11	<1
Phosphorus									
Phosphorus applied (pounds/acre)	24.5	17.0	7.5	19.8	17.5	2.3	14.7	13.4	1.3
Phosphorus in crop yield removed at harvest (pounds/acre)	11.9	11.2	0.7	14.0	13.0	1.0	13.3	12.9	0.4
Total phosphorus loss for all loss pathways (pounds/acre)	7.0	2.1	4.9	2.0	1.4	0.7	1.5	0.8	0.7
Loss of phosphorus to surface water, including waterborne sediment (pounds/acre)	6.8	1.9	4.9	1.9	1.3	0.7	1.4	0.7	0.7
Pesticide loss									
Mass loss of pesticides for all pathways (grams of active ingredient/hectare)	23	11	11	11	9	2	6	5	1
Surface water pesticide risk indicator for aquatic ecosystem	2.40	1.93	0.47	1.50	1.35	0.15	1.54	1.39	0.15
Surface water pesticide risk indicator for humans	0.49	0.39	0.10	0.33	0.31	0.02	0.20	0.19	0.01

*Critical undertreated acres have a high need for additional treatment. Non-critical undertreated acres have a moderate need for additional treatment.
** Gain in soil organic carbon.

Similarly, diminishing returns were pronounced for nitrogen and phosphorus loss. Total nitrogen loss would be reduced by an average of 32 pounds per acre per year on the 434,212 critical undertreated acres and 27 pounds per acre on the 189,276 undertreated acres with a moderate need for treatment, but only 2 pounds per acre for the remaining 222,113 acres.

Total phosphorus loss would be reduced by an average of 4.9 pounds per acre per year on the 434,212 critical undertreated acres, compared to a reduction of only 0.7 pounds per acre for the 189,276 undertreated acres and the 222,113 acres with a low need for additional treatment.

Diminishing returns for reduction in environmental risk for pesticides are also evident to some extent because of the additional soil erosion control treatment.

This rudimentary assessment of diminishing returns ignores the cost of treatment and is focused only on reducing edge-of-field losses. If the cost of treatment for the critical undertreated acres is substantially greater than for the non-critical undertreated acres, the optimal strategy would be to treat a mix of critical and non-critical undertreated acres so as to maximize total edge-of-field savings for a given level of expenditure. If the objective of the conservation treatment was specifically to protect water quality, the relative environmental benefits of sediment and nutrient reductions would also need to be considered.

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

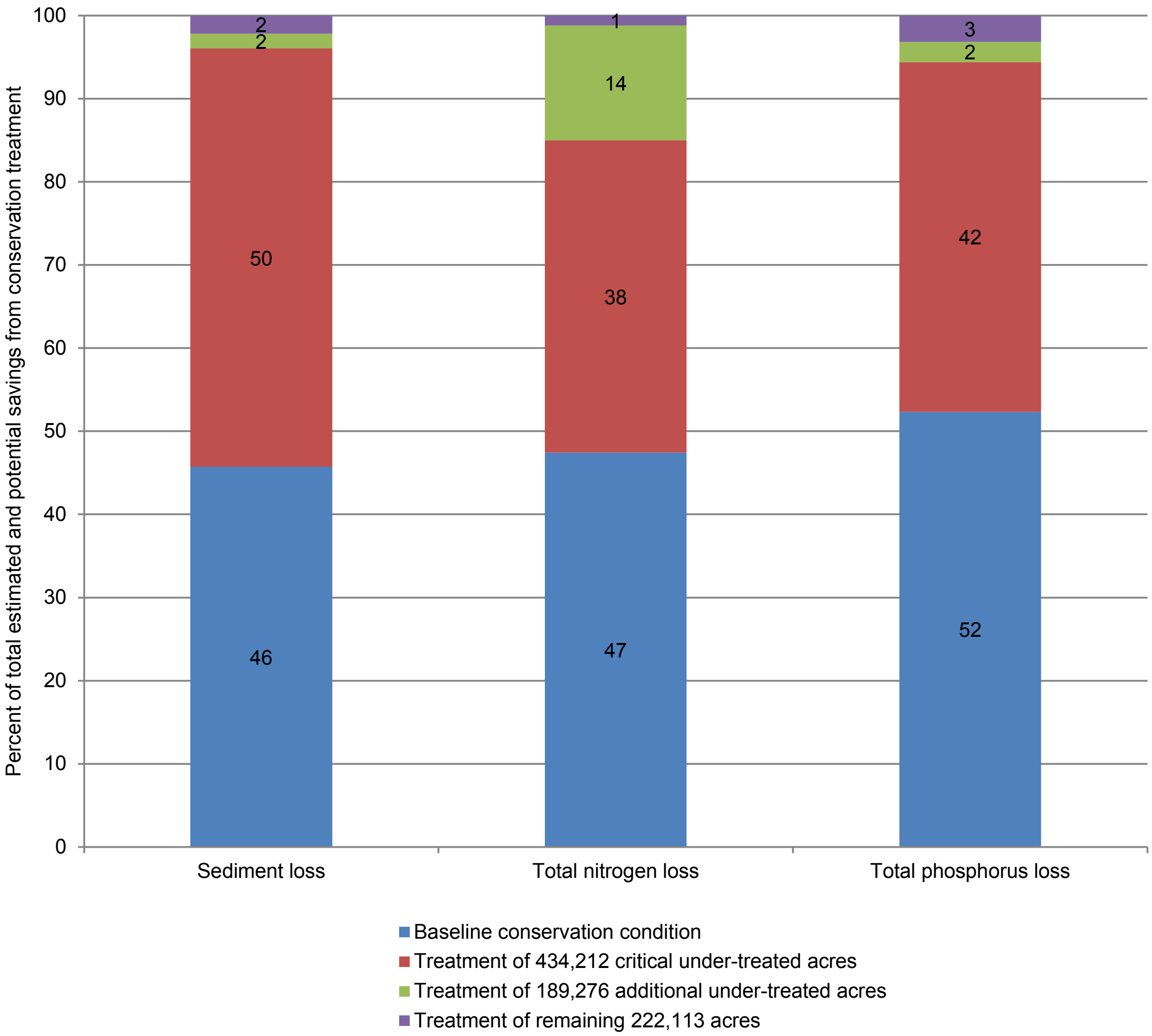
Potential sediment and nutrient savings from additional conservation treatment are contrasted to estimated savings for the conservation practices in use in 2003–06 in figure 52. The no-practice scenario represents the maximum losses that would be expected without any conservation practices in use. Treatment of *all acres* with nutrient management and erosion control practices was used to represent a "full-treatment" condition. The difference in sediment and nutrient loss between these two scenarios represents the maximum savings possible for conservation treatment, which totaled 3.6 million tons of sediment, 18,685 tons of nitrogen, and 2,531 tons of phosphorus for the Delaware River Basin (fig. 52).

For sediment loss, about 46 percent of the potential savings are accounted for by the conservation practices already in use, as represented by the baseline conservation condition (fig. 52). Additional treatment of the 434,212 critical undertreated acres would account for another 50 percent of the potential sediment savings. Treatment of the 189,276 undertreated acres with a moderate need for treatment would account for about 2 percent of the potential savings. Treatment of the 222,113 adequately treated acres would account for the last 2 percent of potential sediment savings.

For nitrogen loss, about 47 percent of the potential savings are accounted for by the conservation practices already in use, as represented by the baseline conservation condition (fig. 52). Additional treatment of the 434,212 critical undertreated acres would account for another 38 percent of the potential nitrogen savings. Treatment of the 189,276 undertreated acres with a moderate need for treatment would account for about 14 percent of the potential savings. Treatment of the 222,113 adequately treated acres would account for the last 1 percent of potential nitrogen savings.

For phosphorus loss, about 52 percent of the potential savings are accounted for by the conservation practices already in use, as represented by the baseline conservation condition (fig. 52). Additional treatment of the 434,212 critical undertreated acres would account for another 42 percent of the potential phosphorus savings. Treatment of the 189,276 undertreated acres with a moderate need for treatment would account for about 2 percent of the potential savings. Treatment of the 222,113 adequately treated acres would account for the last 3 percent of potential phosphorus savings.

Figure 52. 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 Delaware River Basin



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 434,212 critical undertreated acres*	Potential savings from treatment of 189,276 additional undertreated acres*	Potential savings from treatment of remaining 222,113 acres*	Total estimated and potential savings from conservation treatment
Sediment	1,634,592	1,798,480	64,431	77,292	3,574,795
Nitrogen	8,862	7,015	2,585	223	18,685
Phosphorus	1,325	1,064	62	80	2,531

*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 undertreated acres have a high need for additional treatment. Undertreated acres have either a high or moderate need for additional treatment.

Expected regional results assuming all undertreated acres were treated

As shown in figure 52, the potential for reducing overall field-level losses with additional conservation practices is high in this region. Table 34 presents estimates of how treatment of only the 434,212 critical undertreated 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 434,212 acres with model results from the baseline conservation condition for the remaining acres.

Compared to the baseline conservation condition, treating the 434,212 critical undertreated acres with soil erosion control practices *and* nutrient management practices would, for the region as a whole (table 34)—

- reduce sediment loss in the region to an average of 0.37 tons per acre per year, an 85-percent reduction from the baseline conservation condition;
- reduce total nitrogen loss by 34 percent, on average:
  - reduce nitrogen loss with surface runoff (sediment adsorbed and soluble) by 64 percent, and
  - reduce nitrogen loss in subsurface flows by 24 percent;
- reduce phosphorus lost to surface water (sediment adsorbed and soluble) by 58 percent; and
- reduce environmental risk from loss of pesticide residues by 12 to 13 percent.

Compared to the baseline conservation condition, treating all 623,487 undertreated 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 88 percent on average;
- reduce total nitrogen loss by 47 percent:
  - reduce nitrogen loss with surface runoff (sediment adsorbed and soluble) by 68 percent, and
  - reduce nitrogen loss in subsurface flows by 41-percent (to an average loss of 17 pounds per acre);
- reduce phosphorus lost to surface water by 62 percent; and
- reduce environmental risk from loss of pesticide residues by 14 percent.

These reductions in sediment loss, nitrogen lost with surface water, and environmental risk from loss of pesticide residues are mostly due to the erosion control practices, as shown in table 35. The additional nutrient management practices accounted for a significant portion of the reductions in phosphorus lost to surface water and essentially all of the reduction in nitrogen loss in subsurface flows.

The effects of treating the undertreated acres for the region as a whole are graphically shown in figures 53 through 59. In these figures the model results for the baseline distribution are compared to the distributions for two levels of treatment with soil erosion control and nutrient management practices: (1) treatment of the 434,212 critical undertreated acres, and (2) treatment of all 623,487 undertreated acres. 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 undertreated acres. For example, 32 percent of the acres in the Delaware River Basin 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 critical undertreated acres (434,212 acres) with water erosion control practices would reduce the acres exceeding sediment loss of 2 tons per acre per year to less than 1 percent of cropped acres (fig. 53).

Soil organic carbon would be minimally affected by the additional soil erosion control and nutrient management practices (fig. 54). 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 54 shows that the percentage of acres building soil organic carbon would increase from 25 percent for the baseline conservation condition to 32 percent with additional conservation treatment of all the undertreated acres. Acres with highest average annual decreases in soil organic carbon in the baseline would benefit the most.

Treatment of critical undertreated acres with water erosion control *and* nutrient management would reduce the acres exceeding 15 pounds per acre of nitrogen lost with runoff from 30 percent for the baseline to less than 2 percent (fig. 55).

About 35 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 434,212 critical undertreated acres with nutrient management practices would reduce this percentage to 28 percent of cropped acres (fig. 56). Treatment of all 623,487 undertreated acres would reduce the percentage to 19 percent.

For total nitrogen loss to all pathways, 44 percent of the acres in the baseline conservation condition exceed losses of 40 pounds per acre per year. Treating the most critical undertreated acres would reduce the acres exceeding this level of loss to 20 percent (fig. 57). Expanding the treatment to include all undertreated acres would further reduce the acres exceeding 40 pounds per acre to 14 percent.

Acres exceeding 4 pounds per acre of phosphorus lost to surface water would be reduced from 37 percent for the baseline to 11 percent by treating the critical acres and to 9 percent by treating all undertreated acres (fig. 58).

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 5 percent for the region as a whole if the 623,487 undertreated acres were fully treated with additional soil erosion control and nutrient management practices (table 35). Figure 59 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.

Table 34. Conservation practice effects for the region as a whole* after additional treatment of 434,212 critical undertreated acres (acres with a *high* need for conservation treatment) in the Delaware River Basin

	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)	7.1	6.6	7%	6.6	7%
Subsurface water flow (inches)	11.9	12.4	-4%	12.4	-4%
Erosion and sediment loss					
Wind erosion (tons/acre)	0.04	0.04	6%	0.04	5%
Sheet and rill erosion (tons/acre)	1.70	0.73	57%	0.74	56%
Sediment loss at edge of field due to water erosion (tons/acre)	2.49	0.36	85%	0.37	85%
Soil organic carbon					
Change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)	-103	-50	--	-58	--
Nitrogen					
Nitrogen sources					
Atmospheric deposition	9	9	0%	9	0%
Bio-fixation by legumes	31	30	2%	31	0%
Nitrogen applied (pounds/acre)	80	79	2%	67	16%
All nitrogen sources	119	118	1%	106	11%
Nitrogen in crop yield removed at harvest (pounds/acre)	82	81**	<1%	79	3%
Total nitrogen loss for all loss pathways (pounds/acre)	48.5	40.4	17%	31.9	34%
Loss of nitrogen with surface runoff, including waterborne sediment (pounds/acre)	13.6	5.3	61%	4.9	64%
Nitrogen loss in subsurface flows (pounds/acre)	29.0	29.3	-1%	22.2	24%
Phosphorus					
Phosphorus applied (pounds/acre)	20.9	20.8**	1%	17.1	18%
Phosphorus in crop yield removed at harvest (pounds/acre)	12.7	12.7	1%	12.4	3%
Total phosphorus loss for all loss pathways (pounds/acre)	4.4	2.6	41%	1.9	57%
Loss of phosphorus to surface water, including waterborne sediment (pounds/acre)	4.3	2.5	42%	1.8	58%
Pesticide loss					
Mass loss of pesticides for all pathways (grams of active ingredient/hectare)	16	10	38%	10	37%
Surface water pesticide risk indicator for aquatic ecosystems	1.97	1.73	12%	1.73	12%
Surface water pesticide risk indicator for humans	0.38	0.33	13%	0.33	13%

* Results presented for the region as a whole combine model output for the 434,212 treated acres with model results from the baseline conservation condition for the remaining acres.

** Total nitrogen and phosphorus applied were slightly 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 35. Conservation practice effects for the region as a whole* after additional treatment of 623,487 undertreated acres (acres with a *high* or *moderate* need for conservation treatment) in the Delaware River Basin

Model simulated outcome	Baseline conservation condition	Treatment with erosion control practices		Treatment with erosion control and nutrient management practices	
	Average annual amount	Average annual amount	Percent reduction	Average annual amount	Percent reduction
Water flow					
Surface water runoff (inches)	7.1	6.5	9%	6.5	9%
Subsurface water flow (inches)	11.9	12.5	-5%	12.5	-5%
Erosion and sediment loss					
Wind erosion (tons/acre)	0.04	0.04	6%	0.04	7%
Sheet and rill erosion (tons/acre)	1.70	0.67	61%	0.68	60%
Sediment loss at edge of field due to water erosion (tons/acre)	2.49	0.29	89%	0.29	88%
Soil organic carbon					
Change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)	-103	-48	--	-57	--
Nitrogen					
Nitrogen sources					
Atmospheric deposition	9	9	0%	9	0%
Bio-fixation by legumes	31	30	2%	31	-1%
Nitrogen applied (pounds/acre)	80	78*	3%	59	27%
All nitrogen sources	119	117	2%	99	18%
Nitrogen in crop yield removed at harvest (pounds/acre)	82	81	1%	78	5%
Total nitrogen loss for all loss pathways (pounds/acre)	48.5	39.6	18%	25.8	47%
Loss of nitrogen with surface runoff, including waterborne sediment (pounds/acre)	13.6	4.9	64%	4.4	68%
Nitrogen loss in subsurface flows (pounds/acre)	29.0	29.0	0%	17.1	41%
Phosphorus					
Phosphorus applied (pounds/acre)	20.9	20.7*	1%	16.5	21%
Phosphorus in crop yield removed at harvest (pounds/acre)	12.7	12.6	1%	12.2	4%
Total phosphorus loss for all loss pathways (pounds/acre)	4.4	2.5	43%	1.8	60%
Loss of phosphorus to surface water, including waterborne sediment (pounds/acre)	4.3	2.4	45%	1.6	62%
Pesticide loss					
Mass loss of pesticides for all pathways (grams of active ingredient/hectare)	16	9	41%	9	40%
Surface water pesticide risk indicator for aquatic ecosystems	1.97	1.69	14%	1.70	14%
Surface water pesticide risk indicator for humans	0.38	0.32	15%	0.32	14%

* Results presented for the region as a whole combine model output for the 623,487 treated acres with model results from the baseline conservation condition for the remaining acres.
** Total nitrogen and phosphorus applied were 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.

Figure 53. Estimates of average annual sediment loss for undertreated acres treated with water erosion control *and* nutrient management compared to the baseline conservation condition and the no-practice scenario, Delaware River Basin

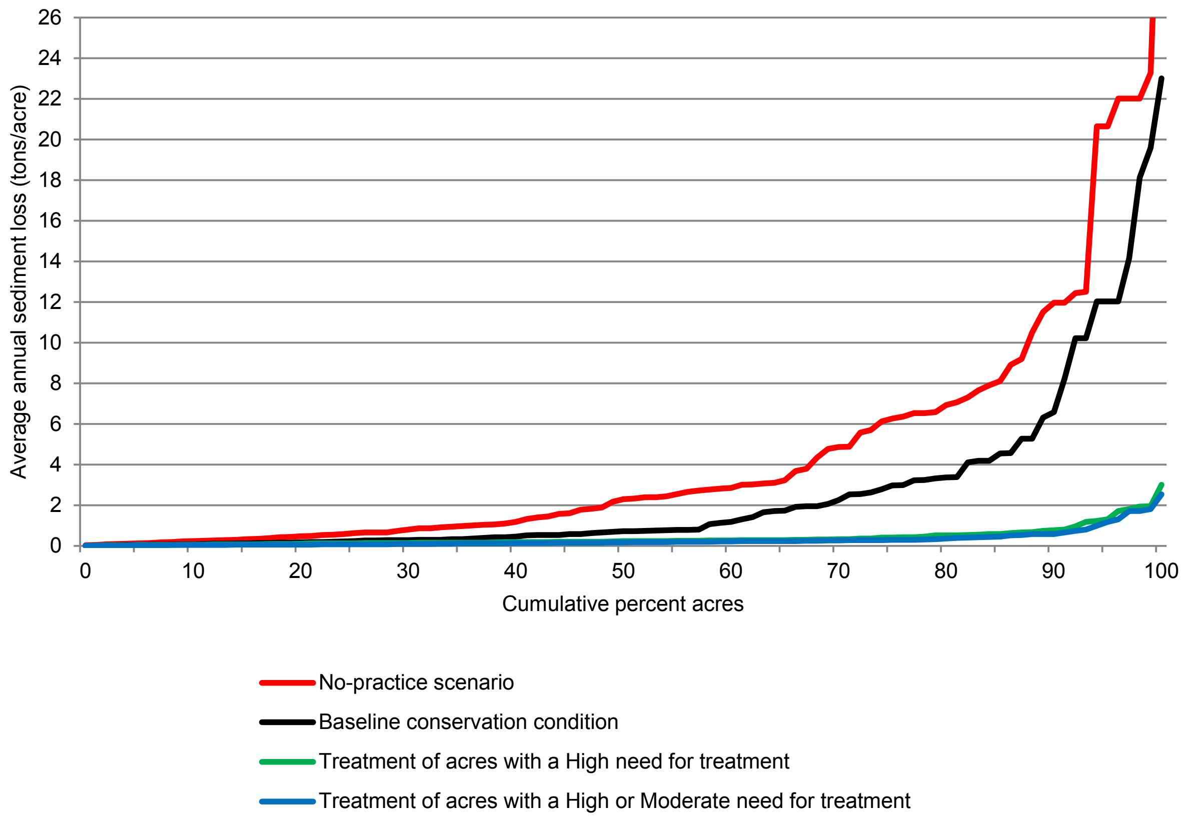


Figure 54. Estimates of average annual change in soil organic carbon for undertreated acres treated with water erosion control *and* nutrient management compared to the baseline conservation condition and the no-practice scenario, Delaware River Basin

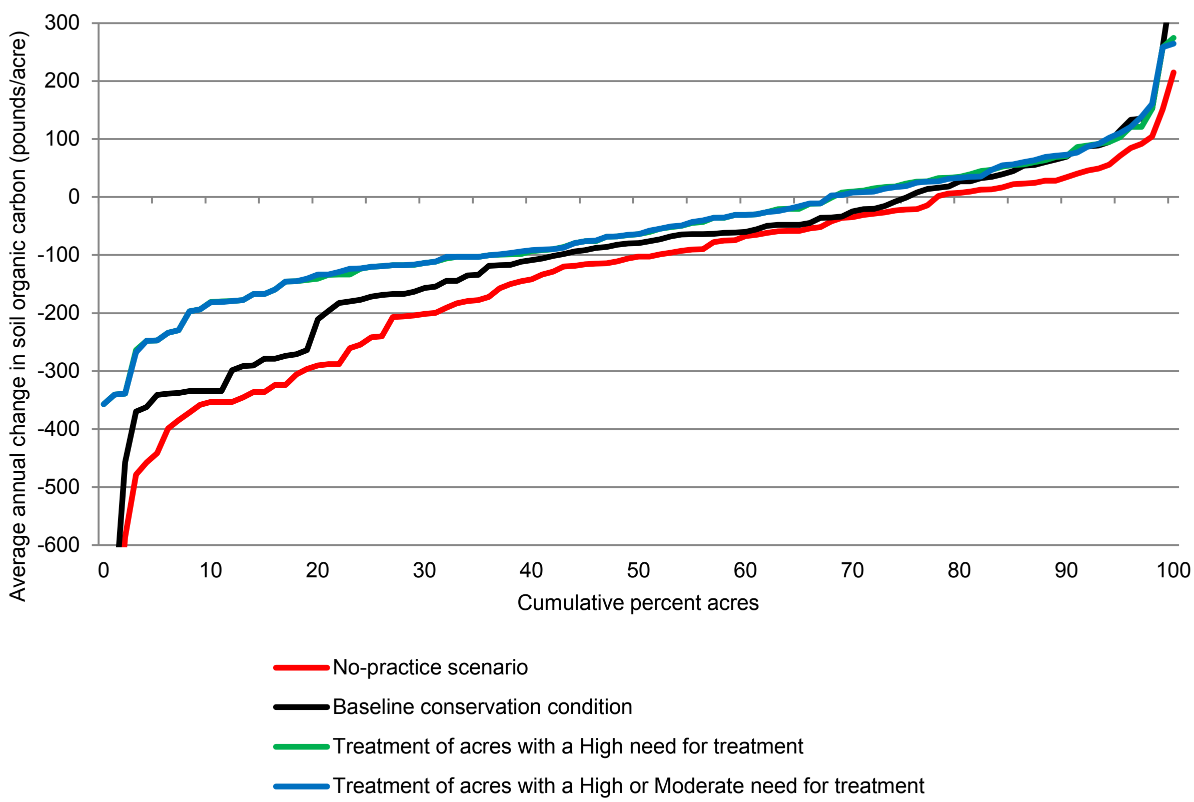


Figure 55. Estimates of average annual loss of nitrogen with surface runoff for undertreated acres treated with water erosion control *and* nutrient management compared to the baseline conservation condition and the no-practice scenario, Delaware River Basin

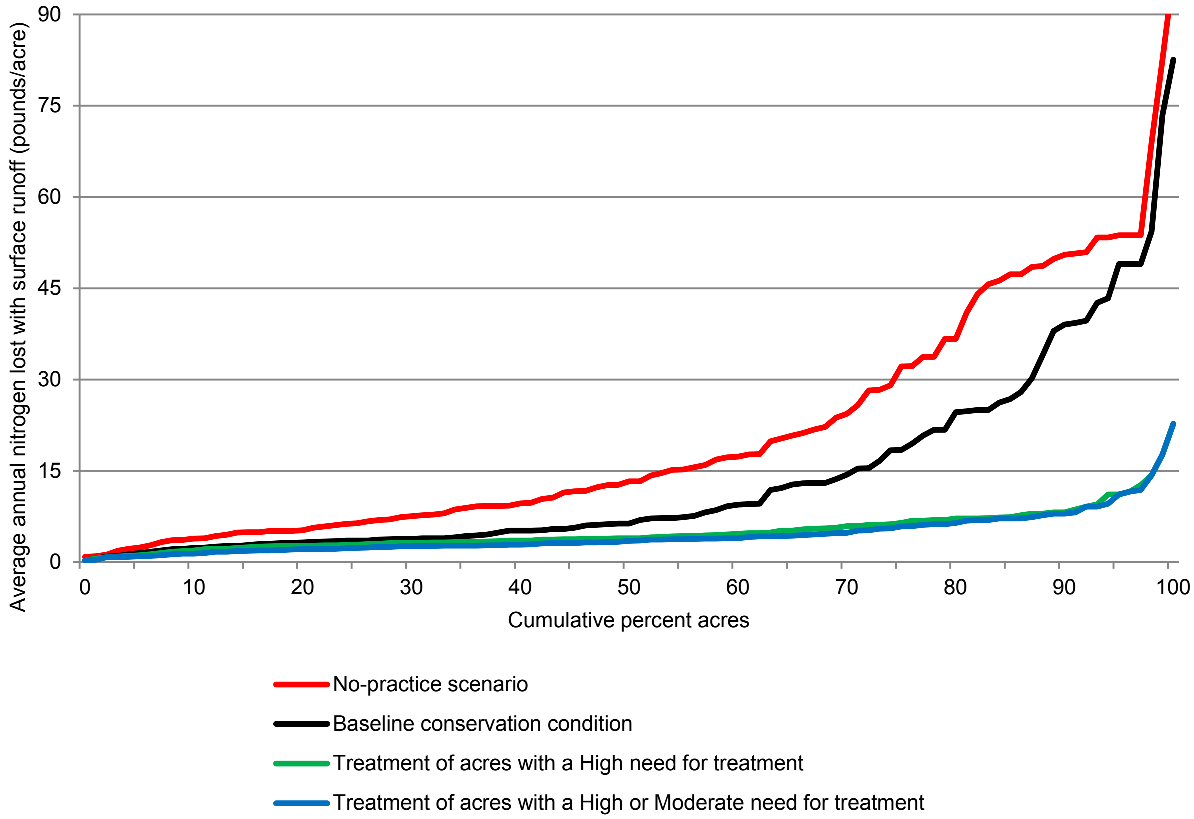


Figure 56. Estimates of average annual loss of nitrogen in subsurface flows for undertreated acres treated with water erosion control *and* nutrient management compared to the baseline conservation condition and the no-practice scenario, Delaware River Basin

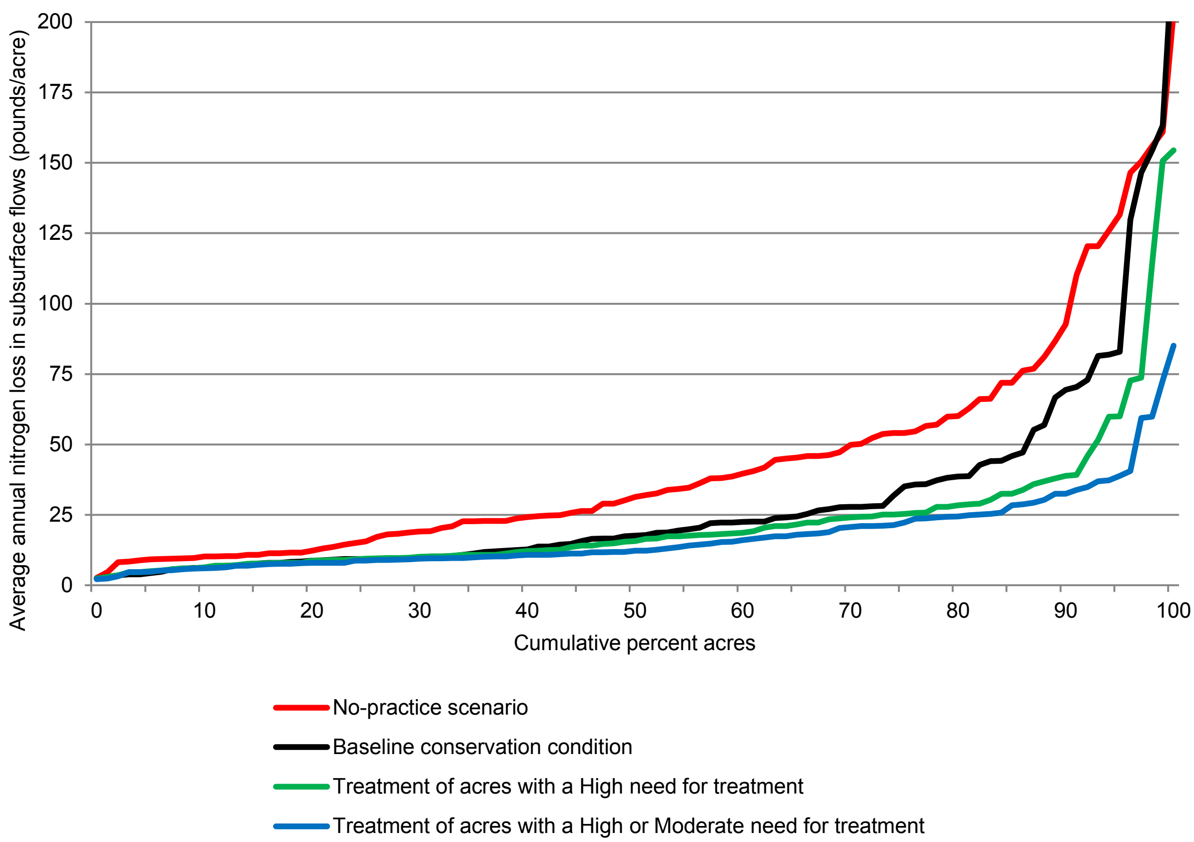


Figure 57. Estimates of average annual total nitrogen loss for undertreated acres treated with water erosion control *and* nutrient management compared to the baseline conservation condition and the no-practice scenario, Delaware River Basin

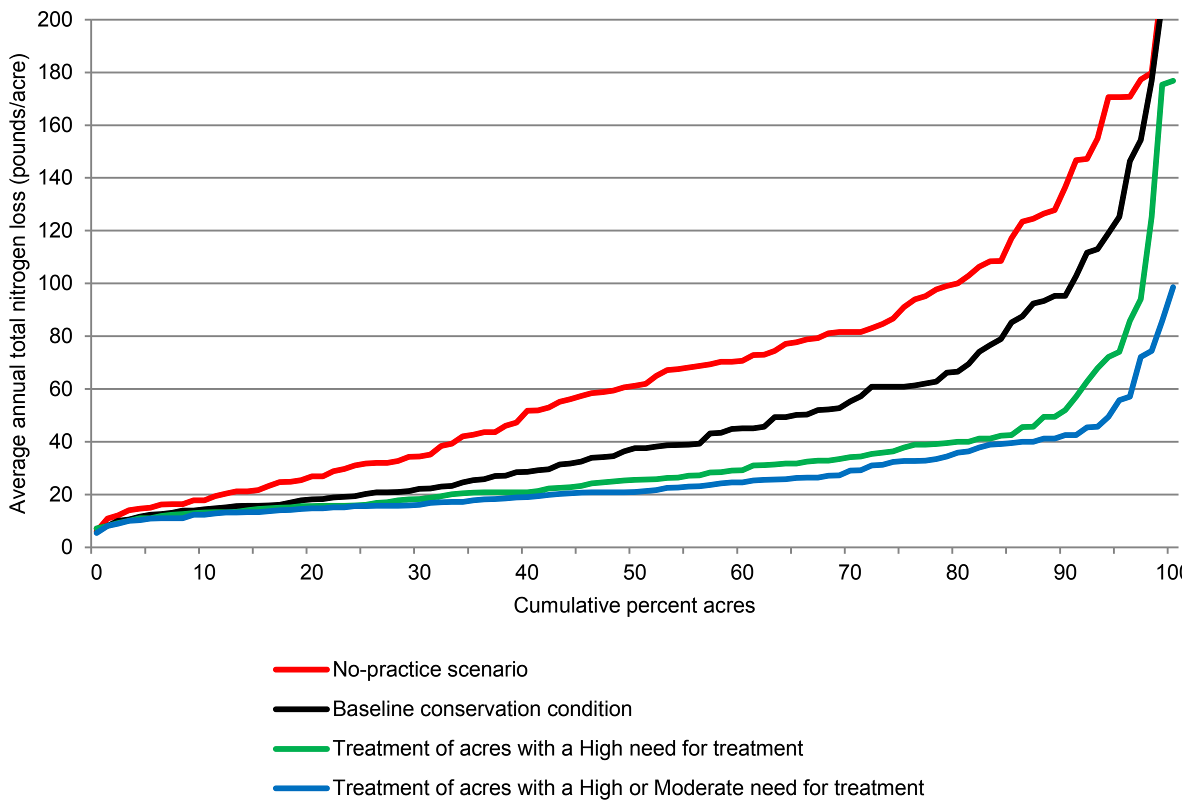
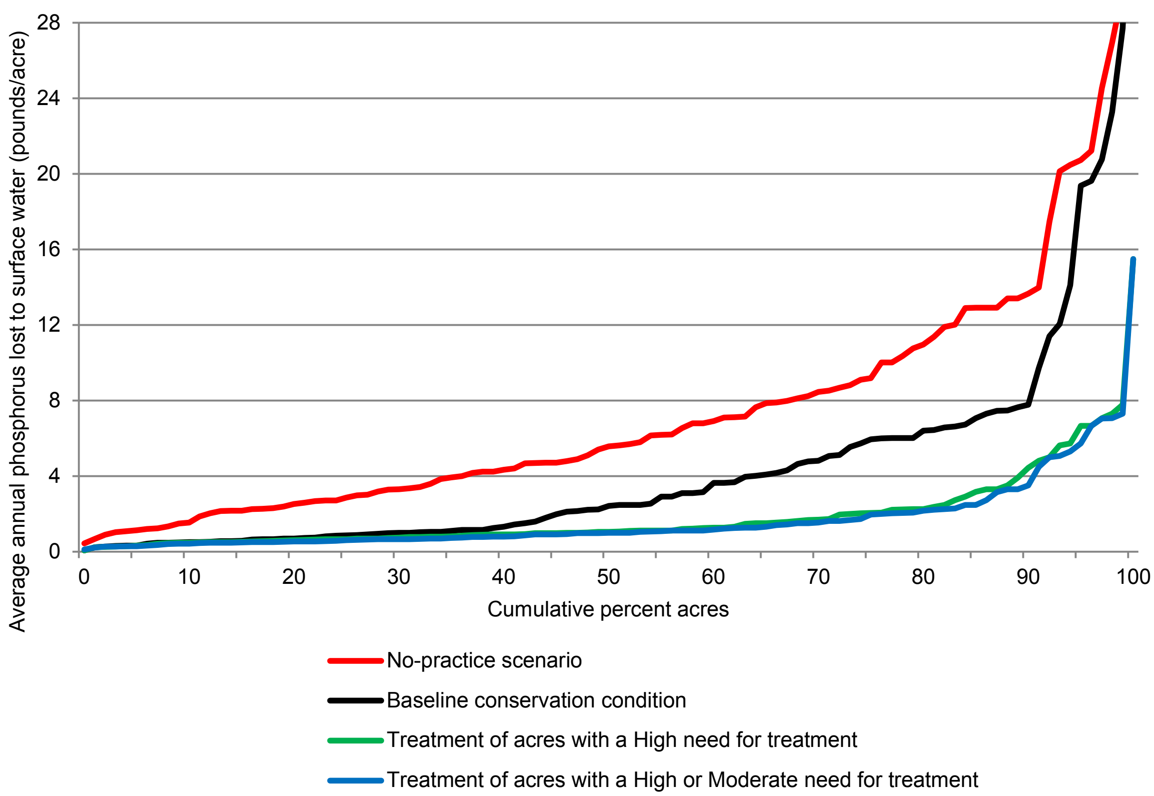
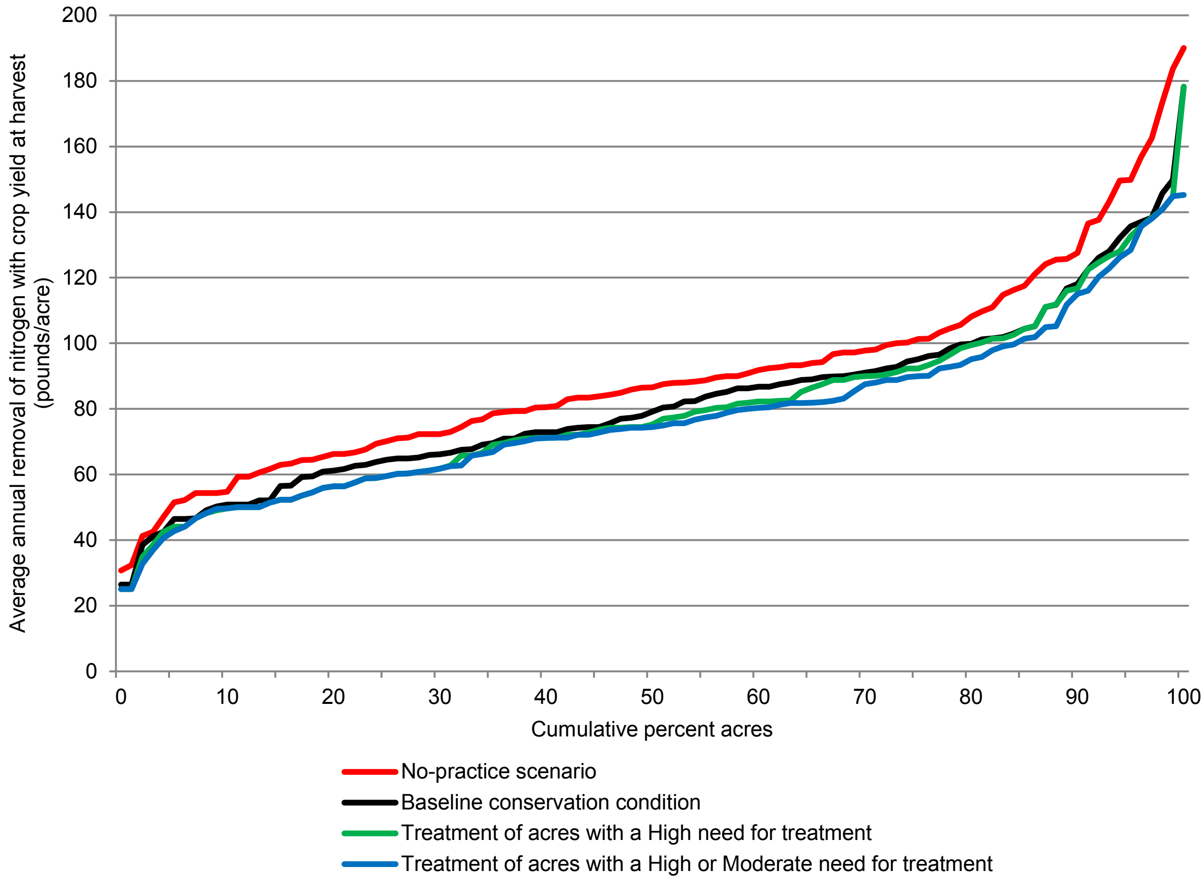


Figure 58. Estimates of average annual phosphorus lost to surface water (sediment attached and soluble)* for undertreated acres treated with water erosion control *and* nutrient management compared to the baseline conservation condition and the no-practice scenario, Delaware River Basin



* 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 59. Estimates of average annual removal of nitrogen with crop yield at harvest for undertreated acres treated with water erosion control *and* nutrient management compared to the baseline conservation condition and the no-practice scenario, Delaware River Basin



Chapter 7
Summary of Findings

Evaluation of Practices in Use

The first Federal conservation efforts on cropland were focused primarily on water management and soil erosion control. Structural practices such as waterways, terraces, and diversions were installed along with supporting practices such as contour farming and stripcropping. Conservation tillage emerged in the 1960s and 1970s as a key management practice for enhancing soil quality and further reducing soil erosion. The conservation compliance provisions in the 1985 Farm Bill sharpened the focus to treatment of the most erodible acres—highly erodible land. This legislation created the Conservation Reserve Program as a mechanism for establishing long-term conserving cover on the most erodible cropland through multi-year contracts with landowners. More recently, the focus has shifted from soil conservation and sustainability to a broader goal of reducing all pollution impacts associated with agricultural production. Prominent among new concerns are the environmental effects of nutrient and pesticide export from farm fields.

The application of conservation practices in the Delaware River Basin reflects this history of Federal conservation programs and technical assistance. An assessment, based on a farmer survey representing practice use and farming activities for the period 2003–06, found the following:

- Structural practices for controlling water erosion are in use on 48 percent of cropped acres (table 6). Structural practices designed to control water erosion are in use on 64 percent of the acres designated as highly erodible land and 33 percent of the remaining acres.
- Reduced tillage is common in the region; 77 percent of the cropped acres meet criteria for either no-till (32 percent) or mulch till (45 percent) (table 7). All but 12 percent of the acres had evidence of some kind of reduced tillage on at least one crop in the rotation.
- About 25 percent of cropped acres are gaining soil organic carbon (fig. 6).
- Producers use either residue and tillage management practices or structural practices, or both, on 95 percent of cropped acres (table 8).
- 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 (table 9).
  - About 4 percent of cropped acres have no nitrogen applied. An additional 62 percent of cropped acres meet criteria for timing of nitrogen applications on all crops in the rotation, 30 percent meet criteria for method of application, and 43 percent meet criteria for rate of application.
  - Less than 1 percent of cropped acres have no phosphorus applied. An additional 69 percent of cropped acres meet criteria for timing of phosphorus applications on all crops in the rotation, 52 percent meet criteria for method of application, and 48 percent meet criteria for rate of application.
  - 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 11 percent of cropped acres.
  - Good phosphorus management practices (appropriate rate, timing, and method) are in use on 26 percent of the acres on all crops during every year of production.
  - Only about 12 percent of cropped acres meet nutrient management criteria for both nitrogen and phosphorus management.
- During the 2003–06 period of data collection, cover crops were used on 4 percent of the acres in the region.
- The Integrated Pest Management (IPM) indicator showed that only about 16 percent of the acres were being managed with a relatively high level of IPM (fig. 9).

Annual precipitation over the 47-year simulation averaged about 45 inches for cropped acres in this region. About 13 percent of the cropped acres are irrigated, at an average application of 12.7 inches per year (table 12).

Effects of Conservation Practices

Model simulation results show that, for cropped acres in the region, *on average* conservation practices have—

- reduced surface water flow from fields by 11 percent, re-routing most of the water to subsurface flow pathways (table 12);
- reduced wind erosion by 39 percent, from 0.07 ton per acre without conservation practices to 0.04 ton per acre with conservation practices (table 13);
- reduced sediment loss from fields caused by water erosion by 44 percent, from 4.43 tons per acre without conservation practices to 2.49 tons per acre with conservation practices (table 14);
- reduced total nitrogen loss (volatilization, denitrification, surface runoff, and subsurface flow losses) from fields by 30 percent, from 69.5 pounds per acre without conservation practices to 48.5 pounds per acre with conservation practices (table 17):
  - reduced nitrogen lost with surface runoff (attached to sediment and in solution) by 34 percent, from 20.7 pounds per acre without conservation practices to 13.6 pounds per acre with conservation practices;
  - reduced nitrogen loss in subsurface flows by 33 percent, from 43.0 pounds per acre without conservation practices to 29.0 pounds per acre with conservation practices;
- reduced total phosphorus loss from fields by 41 percent, from 7.6 pounds per acre without conservation practices to 4.4 pounds per acre with conservation practices (table 18); and
- reduced pesticide loss from fields to surface water, resulting in a 35-percent reduction in edge-of-field pesticide risk (all pesticides combined) for aquatic ecosystems and a 27-percent reduction in edge-of-field surface water pesticide risk for humans (table 20).

In this region, conservation practices on cropped acres have a relatively modest effect on soil organic carbon levels (figs. 21 and 22). Conservation practice use in the region has resulted in an average annual gain in soil organic carbon of 37 pounds per acre per year on cropped acres (table 16).

Conservation practices are effective in reducing nitrogen loss in subsurface flows on some acres in this region, but make little difference on other acres and even result in increases in nitrogen loss in subsurface flows for 15 percent of cropped acres (figs. 30 and 31). 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 flow not only redirects the dissolved nitrogen into subsurface flow but also can extract additional nitrogen from the soil as the water passes through the soil profile, including nitrogen produced by legumes such as soybeans (nitrogen biofixation). On about 12 percent of the cropped acres in this region, the rerouting of surface water runoff to subsurface flow pathways, in combination with ineffective or incomplete nutrient management practices, results in sufficient amounts of additional nitrogen being leached from the soil to more than offset the reductions in nitrogen lost with surface runoff and produce a small net increase in total nitrogen loss (fig. 28). Model simulation of additional conservation treatment shows that pairing effective nutrient management practices (consistent use of proper rate, form, timing, *and* method of application) with water erosion control practices could reduce nitrogen loss in subsurface flow to acceptable levels for 81 percent of the cropped acres in this region.

Conservation Treatment Needs

The adequacy of conservation practices in use in the Delaware River Basin for the time period 2003–06 was evaluated to identify conservation treatment needs for four resource concerns (see chapter 5):

- Sediment loss from fields.
- Nitrogen lost with surface runoff (attached to sediment and in solution).
- Nitrogen loss in subsurface flows.
- Phosphorus lost to surface water (includes soluble phosphorus in lateral flow).

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 permeable 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.

Undertreated acres were identified by an imbalance between the level of conservation treatment and the level of inherent vulnerability. Three levels of treatment need were identified:

- Acres with a “high” level of need for conservation treatment consist of the most critical undertreated acres in the region. These are the most vulnerable of the undertreated 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 undertreated 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.

Seventy-four percent of the cropped acres need additional conservation treatment in this region (figs. 50 and 51):

- 51.3 percent of cropped acres (434,212 acres) have a **high** level of need for additional conservation treatment.
- 22.4 percent of cropped acres (189,276 acres) have a **moderate** level of need for additional conservation treatment.

Both erosion control and nutrient management are critical conservation concerns in this region. Most undertreated acres need additional treatment for more than one of the four resource concerns. About one-fourth of the undertreated acres need additional treatment for all four resource concerns (table 26). One third of the undertreated acres need additional treatment for nitrogen leaching only. Twenty-eight percent of undertreated acres need additional treatment for sediment loss and/or nitrogen or phosphorus loss with surface water runoff but do not need additional treatment for nitrogen loss in subsurface flows.

The 434,212 acres with a “high” level of need for conservation treatment lose (per acre per year, on average) 4.4 tons of sediment by water erosion, 7.0 pounds of phosphorus, and 62 pounds of nitrogen (table 27). The 189,276 acres with a “moderate” level of need for conservation treatment lose (per acre per year, on average) 0.4 ton of sediment by water erosion, 2.0 pounds of phosphorus, and 52 pounds of nitrogen. The 222,113 acres with a “low” level of need for conservation treatment lose only (per acre per year, on average) 0.4 ton of sediment by water erosion, 1.5 pounds of phosphorus, and 18 pounds of nitrogen.

Simulation of Additional Conservation Treatment

Model simulations were used to evaluate the potential gains from further conservation treatment in the Delaware River Basin (see chapter 6).

Three sets of additional conservation practices were simulated:

1. Additional wind and water erosion control practices consisting of four types of structural practices—overland flow practices, concentrated flow practices, edge-of-field mitigation—and wind erosion control practices.
2. Application of nitrogen and phosphorus using appropriate rate, timing, and method.
3. Increases in the efficiency of irrigation water application.

Model simulation was used to estimate the gains that could be attained when additional soil erosion control practices, nutrient management practices, and increased irrigation efficiencies are applied in this region (table 33).

- Conservation treatment of the 434,212 critical undertreated acres would reduce sediment loss an average of 4.14 tons per acre per year on those acres. In comparison, additional treatment of the 189,276 undertreated acres with a moderate need for treatment would reduce sediment loss by about 0.34 ton per acre per year on those acres, and treatment of the remaining 222,113 acres would reduce sediment loss by only 0.35 ton per acre per year on those acres, on average.
- Total nitrogen loss would be reduced by an average of 32 pounds per acre per year on the 434,212 critical undertreated acres and 27 pounds per acre for the 189,276 undertreated acres with a moderate need for treatment, compared to a reduction of only 2 pounds per acre for the remaining 222,113 acres.
- Total phosphorus loss would be reduced by an average of 4.9 pounds per acre per year on the 434,212 critical undertreated acres, compared to a reduction of only 0.7 pound per acre for the 189,276 undertreated acres with a moderate need for treatment and for the 222,113 acres with a low need for additional treatment.

Model simulations demonstrated that sediment and nitrogen losses with surface runoff could be effectively controlled in the region with additional erosion control practices. However, model simulations also showed that a suite of practices that includes both soil erosion control and consistent nutrient management is often *required* to adequately address both soil erosion *and* nutrient loss through all loss pathways. Treatment with combinations of soil erosion control practices and nutrient management makes applied nutrients more available for use by crops and thus significantly reduces the rerouting of soluble nitrogen and phosphorus to subsurface loss pathways.

Compared to the baseline conservation condition, treating all 623,487 undertreated 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 88 percent on average;
- reduce total nitrogen loss by 47 percent:
  - reduce nitrogen loss with surface runoff (sediment adsorbed and soluble) by 68 percent, and
  - reduce nitrogen loss in subsurface flows by 41 percent;
- reduce phosphorus lost to surface water by 62 percent; and
- reduce environmental risk from loss of pesticide residues by 14 percent.

The potential for achieving additional field-level savings from further conservation treatment is high in this region. Conservation practices in use in 2003–06 achieved 46 percent of potential reductions in sediment loss, 47 percent for nitrogen, and 52 percent for phosphorus. By treating all 623,486 undertreated acres in the region with additional erosion control and nutrient management practices, an additional 52 percent in savings would be attained for sediment, 52 percent for nitrogen, and 44 percent for phosphorus. The bulk of these savings would be achieved by treating the critical undertreated acres. To achieve 100 percent of potential savings (i.e., an additional 2 percent for sediment, 1 percent for nitrogen, and 3 percent for phosphorus), additional conservation treatment for the remaining 222,113 acres with a low need for additional treatment would be required, which would result in very small conservation gains on a per-acre basis.

References

Bruulsema, T., Lemunyon, J., and Herz, B. 2009. Know your fertilizer rights. Crops and Soils 42(2), pp 13-16.

Coble, H. 1998. Measuring the Resilience of IPM Systems—The PAMS Diversity Index. Unpublished manuscript. U.S. Department of Agriculture. 1998.

Daly, C., R. P. Neilson, and D. L. Phillips. 1994: A statistical-topographic model for mapping climatological precipitation over mountainous terrain. J. Appl. Meteor., 33, 140–158.

Di Luzio M., G. L. Johnson, C. Daly, Jon K. Eischeid, J.G. Arnold. 2008. Constructing Retrospective Gridded Daily Precipitation and Temperature Datasets for the Conterminous United States. Journal of Applied Meteorology and Climatology. 47(2): 475–497.

Eischeid, Jon K., Phil A. Pasteris; Henry F. Diaz, Marc S. PLantico, and Neal J. Lott. 2000. Creating a serially complete, national daily time series of temperature and precipitation for the western United States." Journal of Applied Meteorology 39 (September):1580-1591.

Gassman, Philip W., Jimmy R. Williams, Verel W. Benson, R. Cesar Izaurralde, Larry Hauck, C. Allan Jones, Jay D. Atwood, James Kiniry, and Joan D. Flowers. 2005. Historical Development and Applications of the EPIC and APEX Models. Working Paper 05-WP 397, Center for Agricultural and Rural Development, Iowa State University, Ames, IA.

Gassman, P.W., J.R. Williams, S. Wang, A. Saleh, E. Osei, L. Hauck, C. Izaurralde, and J. Flowers. 2009. The Agricultural Policy Environmental Extender (APEX) model: An emerging tool for landscape and watershed environmental analyses. Technical Report 09-TR 49. CARD, Iowa State Univ., Ames, IA. Available at: http://www.card.iastate.edu/publications/synopsis.aspx?id=1101.

Gassman, P.W., J.R. Williams, S. Wang, A. Saleh, E. Osei, L. Hauck, C. Izaurralde, and J. Flowers. 2010. The Agricultural Policy Environmental Extender (APEX) model: An emerging tool for landscape and watershed environmental analyses. *Trans. of the ASABE*.

Goebel, J.J., and H.D. Baker. 1987. The 1982 National Resources Inventory Sample Design and Estimation Procedures. Statistical Laboratory, Iowa State University, Ames, IA.

Goebel, J.J. 1998. The National Resources Inventory and its role in U.S. agriculture. *In* Agricultural Statistics 2000. International Statistical Institute, Voorburg, The Netherlands, 181–192.

Goebel, J.J., and R.L. Kellogg. 2002. Using survey data and modeling to assist the development of agri-environmental policy. *In* Conference on Agricultural and Environmental Statistical Applications in Rome. National Statistical Institute of Italy, Rome, Italy, 695–705.

Goss, Don W., Robert L. Kellogg, Joaquin Sanabria, Susan Wallace, and Walt Kniesel. 1998. The National Pesticide Loss Database: A Tool for Management of Large Watersheds. Poster presentation at the 53rd annual Soil and Water Conservation Society conference. San Diego, CA, July 5–9., 1998.

Homer, C., J. Dewitz, J. Fry, M. Coan, N. Hossain, C. Larson, N. Herold, A. McKerrow, J.N. VanDriel and J. Wickham. 2007. Completion of the 2001 National Land Cover Database for the Conterminous United States, Photogrammetric Engineering and Remote Sensing, Vol. 73, No. 4, pp 337-341.

Izaurralde, R. C., J. R. Williams, W. B. McGill, N. J. Rosenberg, M. C. Quiroga Jakas. 2006. Simulating soil C dynamics with EPIC: Model description and testing against long-term data. *Ecol. Model.* 192: 362–384.

Kellogg, R.L., M.S. Maizel, and D.W. Goss. 1992. Agricultural Chemical Use and Ground Water Quality: Where Are the Problem Areas? U.S. Department of Agriculture, Soil Conservation Service.

Kellogg, Robert L., Margaret Maizel, and Don W. Goss. 1994. The potential for leaching of agrichemicals used in crop production: A national perspective. Journal of Soil and Water Conservation 49(3):294–298.

Kellogg, Robert L., Don W. Goss, Susan Wallace, and Klaus Alt. 1997. Potential Priority Watersheds for Protection of Water Quality from Non-Point Sources Related to Agriculture. Poster Presentation at the 52nd Annual Soil and Water Conservation Society Conference. Toronto, Ontario, Canada. July 22–25, 1997.

Kellogg, Robert L. 2000. Potential Priority Watersheds for Protection of Water Quality from Contamination by Manure Nutrients. Presented at the Water Environment Federation's Animal Residuals Management Conference 2000. Kansas City, MO. November 12–14, 2000.

Kellogg, Robert L. Richard F. Nehring, Arthur Grube, Donald W. Goss, and Steven Plotkin. 2002. Environmental indicators of pesticide leaching and runoff from farm fields. *In* Ball, V. Eldon, and George W. Norton (editors), Agricultural Productivity: Measurement and Sources of Growth. Kluwer Academic Publishers, Boston, MA.

Maresch, W., M.R. Walbridge, and D. Kugler. 2008. Enhancing conservation on agricultural landscapes: A new direction for the Conservation Effects Assessment Project. Journal of Soil and Water Conservation, Nov.-Dec. 2008.

Mausbach, M.J., and A.R. Dedrick. 2004. The length we go: Measuring environmental effects of conservation practices. Journal of Soil and Water Conservation, Sept.-Oct. 2004.

National Agricultural Statistics Service (NASS). 2007. Cropland Data Layer. USDA NRCS Geospatial Data Gateway, http://datagateway.nrcs.usda.gov/

Nusser, S.M., and J.J. Goebel. 1997. The National Resources Inventory: A long-term multi-resource monitoring programme. Environmental and Ecological Statistics 4:181–204.

Potter, S.R., S. Andrews, J.D. Atwood, R.L. Kellogg, J. Lemunyon, L. Norfleet, and D. Oman. 2006. Model simulation of soil loss, nutrient loss, and change in soil organic carbon associated with crop production. USDA, Natural Resources Conservation Service, Washington, DC. Available at http://www.nrcs.usda.gov/technical/nri/ceap.

U.S. Department of Agriculture. 1989. The Second RCA Appraisal: Analysis of Conditions and Trends. 280 pages.

U.S. Department of Agriculture. 2011. RCA Appraisal 2011: Soil and Water Resources Conservation Act. 100 pages.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2002. 1997 National Resources Inventory Summary Report. Washington, DC. Available at http://www.nrcs.usda.gov/technical/nri.

United States Department of Agriculture, Natural Resources Conservation Service. 2003. Costs Associated With Development and Implementation of Comprehensive Nutrient Management Plans.

United States Department of Agriculture, Natural Resources Conservation Service. 2007. 2003 National Resources Inventory. http://www.nrcs.usda.gov/technical/nri.

United States Department of Agriculture, National Agricultural Statistics Service. 2009. 2007 Census of Agriculture. Database.

U.S. Geological Survey. 1980. Hydrologic Unit Map of the United States. U.S. Department of the Interior. Washington, DC.

Williams, J. R. 1990. The erosion productivity impact calculator (EPIC) model: A case history. *Phil. Trans. R. Soc. Lond.* 329: 421-428.

Williams, J. R., C. A. Jones, and P. T. Dyke. 1984. A modeling approach to determining the relationship between erosion and soil productivity. *Trans. ASAE* 27(1): 129-144.

Williams, J. R., W. L. Harman, M. Magre, U. Kizil, J. A. Lindley, G. Padmanabhan, and E. Wang. 2006. APEX feedlot water quality simulation. *Trans. ASAE* 49(1): 61-73.

Williams, J. R., R. C. Izaurralde, and E. M. Steglich. 2008. Agricultural Policy/Environmental eXtender Model: Theoretical documentation version 0604. BREC Report # 2008-17. Temple, TX: Texas AgriLIFE Research, Texas A&M University, Blackland Research and Extension Center. Available at: http://epicapex.brc.tamus.edu/downloads/user-manuals.aspx. Accessed 31 January 2010.

Appendix A: Estimates of Margins of Error for Selected Acre 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 the documentation report "NRI-CEAP Cropland Survey Design and Statistical Documentation," referenced on page 5. The sample for cropped acres consists of 186 sample points in the Delaware River Basin. 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 acres 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 selected acre estimates based on the CEAP sample, Delaware River Basin

	Estimated acres	Margin of error
Cropped acres in region	845,600	111,409
Cropping systems		
Corn and soybean only	226,591	75,323
Corn and soybean with close grown crops	158,700	82,216
Corn only	117,327	58,729
Corn with close grown crops	71,486	48,379
Soybean only	65,764	30,882
Vegetables or tobacco with or without other crops	53,235	43,920
Hay-crop mix	99,983	44,712
Remaining crop mixes	52,514	39,034
Use of structural practices (table 6)		
Overland flow control practices	319,667	105,534
Concentrated flow control practices	162,769	90,533
Edge-of-field buffering and filtering practices	47,047	28,191
One or more water erosion control practices	401,780	105,835
Wind erosion control practices	56,105	34,489
Use of cover crops	35,602	33,284
Use of residue and tillage management (table 7)		
Average annual tillage intensity for crop rotation meets criteria for no-till	272,567	76,303
Average annual tillage intensity for crop rotation meets criteria for mulch till	381,509	77,117
Reduced tillage on some crops in rotation but average annual tillage intensity greater than criteria for mulch till	92,291	64,022
Continuous conventional tillage in every year of crop rotation	99,232	43,807

Table A1—continued.

	Estimated acres	Margin of error
Conservation treatment levels for structural practices (fig. 5)		
High level of treatment	36,222	26,076
Moderately high level of treatment	93,345	99,524
Moderate level of treatment	272,213	99,976
Low level of treatment	443,820	104,286
Conservation treatment levels for residue and tillage management (fig. 6)		
High level of treatment	145,823	66,220
Moderately high level of treatment	30,460	19,223
Moderate level of treatment	585,063	104,147
Low level of treatment	84,254	44,440
Conservation treatment levels for nitrogen management (fig. 7)		
High level of treatment	111,981	56,557
Moderately high level of treatment	284,819	85,976
Moderate level of treatment	294,339	71,016
Low level of treatment	154,460	56,491
Conservation treatment levels for phosphorus management (fig. 8)		
High level of treatment	219,804	97,180
Moderately high level of treatment	191,287	77,916
Moderate level of treatment	119,894	63,478
Low level of treatment	314,615	52,686
Conservation treatment levels for IPM (fig. 9)		
High level of treatment	135,495	54,812
Moderate level of treatment	405,436	99,057
Low level of treatment	304,669	90,740
Conservation treatment levels for water erosion control practices (fig. 42)		
High level of treatment	92,912	41,611
Moderately high level of treatment	55,524	39,714
Moderate level of treatment	472,134	113,356
Low level of treatment	225,031	82,973
Conservation treatment levels for nitrogen runoff control (fig. 43)		
High level of treatment	8,072	12,944
Moderately high level of treatment	144,899	54,667
Moderate level of treatment	520,499	102,391
Low level of treatment	172,130	69,832
Conservation treatment levels for phosphorus runoff control (fig. 44)		
High level of treatment	25,465	23,056
Moderately high level of treatment	199,185	62,914
Moderate level of treatment	347,494	90,043
Low level of treatment	273,456	61,020
Soil runoff potential (fig. 45)		
High	209,204	64,436
Moderately high	144,274	58,747
Moderate	122,278	59,727
Low	369,844	82,928
Soil leaching potential (fig. 47)		
High	210,303	78,790
Moderately high	170,312	81,413
Moderate	438,300	117,805
Low	26,685	19,212

Table A1—continued.

	Estimated acres	Margin of error
Level of conservation treatment need by resource concern		
Sediment loss (table 22)		
High (critical undertreated)	313,551	73,742
Moderate (non-critical undertreated)	0	--
Low (adequately treated)	532,049	108,394
Nitrogen loss with surface runoff (sediment attached and soluble) (table 23)		
High (critical undertreated)	261,116	59,598
Moderate (non-critical undertreated)	76,271	54,917
Low (adequately treated)	508,213	113,475
Nitrogen loss in subsurface flows (table 24)		
High (critical undertreated)	114,734	58,393
Moderate (non-critical undertreated)	334,065	75,528
Low (adequately treated)	396,801	90,316
Phosphorus lost to surface water (table 25)		
High (critical undertreated)	312,268	68,378
Moderate (non-critical undertreated)	0	--
Low (adequately treated)	533,332	91,987
Level of conservation treatment need for one or more resource concerns (fig. 51)		
High (critical undertreated)	434,212	89,825
Moderate (non-critical undertreated)	189,276	53,515
Low (adequately treated)	222,113	67,565

END