USDA NRCS
United States Department of Agriculture
Natural Resources Conservation Service

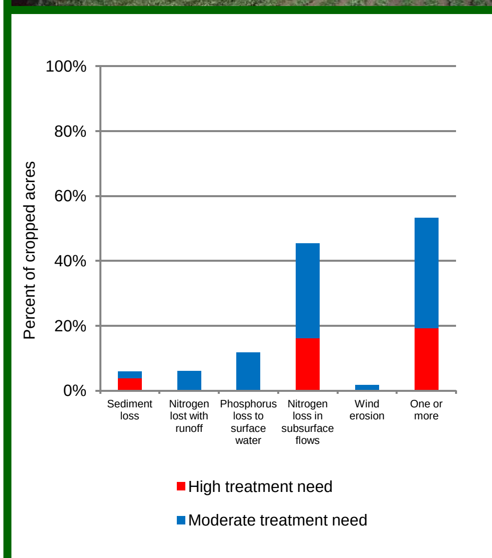
Conservation Effects Assessment Project (CEAP)

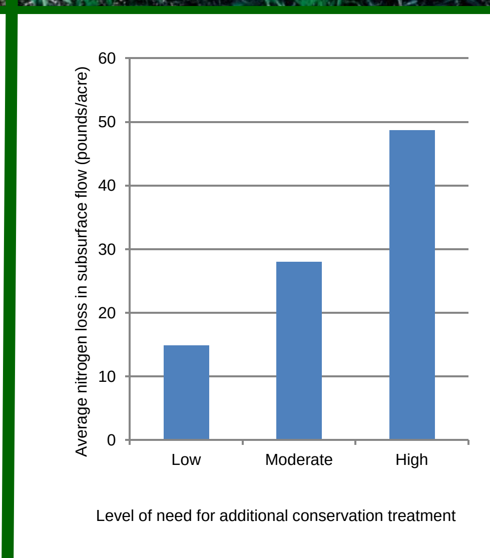
August 2011

Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Great Lakes Region









This page intentionally left blank.

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

CEAP—Strengthening the science base for natural resource conservation

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

CEAP activities are organized into three interconnected efforts:

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

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

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

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

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

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
Jeff Goebel, Beltsville, MD, Statistician
Kevin Ingram, Beltsville, MD, Agricultural Economist
Robert L. Kellogg, Beltsville, MD, Agricultural Economist
Jerry Lemunyon, Fort Worth, TX, Agronomist and Nutrient Management Specialist
Lee Norfleet, Temple, TX, Soil Scientist

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
Evelyn Steglich, Research Assistant
Xiuying (Susan) Wang, Agricultural Engineer
Jimmy Williams, Agricultural Engineer

University of Massachusetts Extension, Amherst, MA

Stephen Plotkin, Water Quality Specialist

The study was conducted under the direction of **Douglas Lawrence**, Deputy Chief for Soil Survey and Resource Assessment, **Michele Laur**, Director for Resource Assessment Division, and **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, **Dave White**, and former NRCS Chiefs **Arlen Lancaster** and **Bruce Knight**.

Acknowledgements

The team thanks Al**ex 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

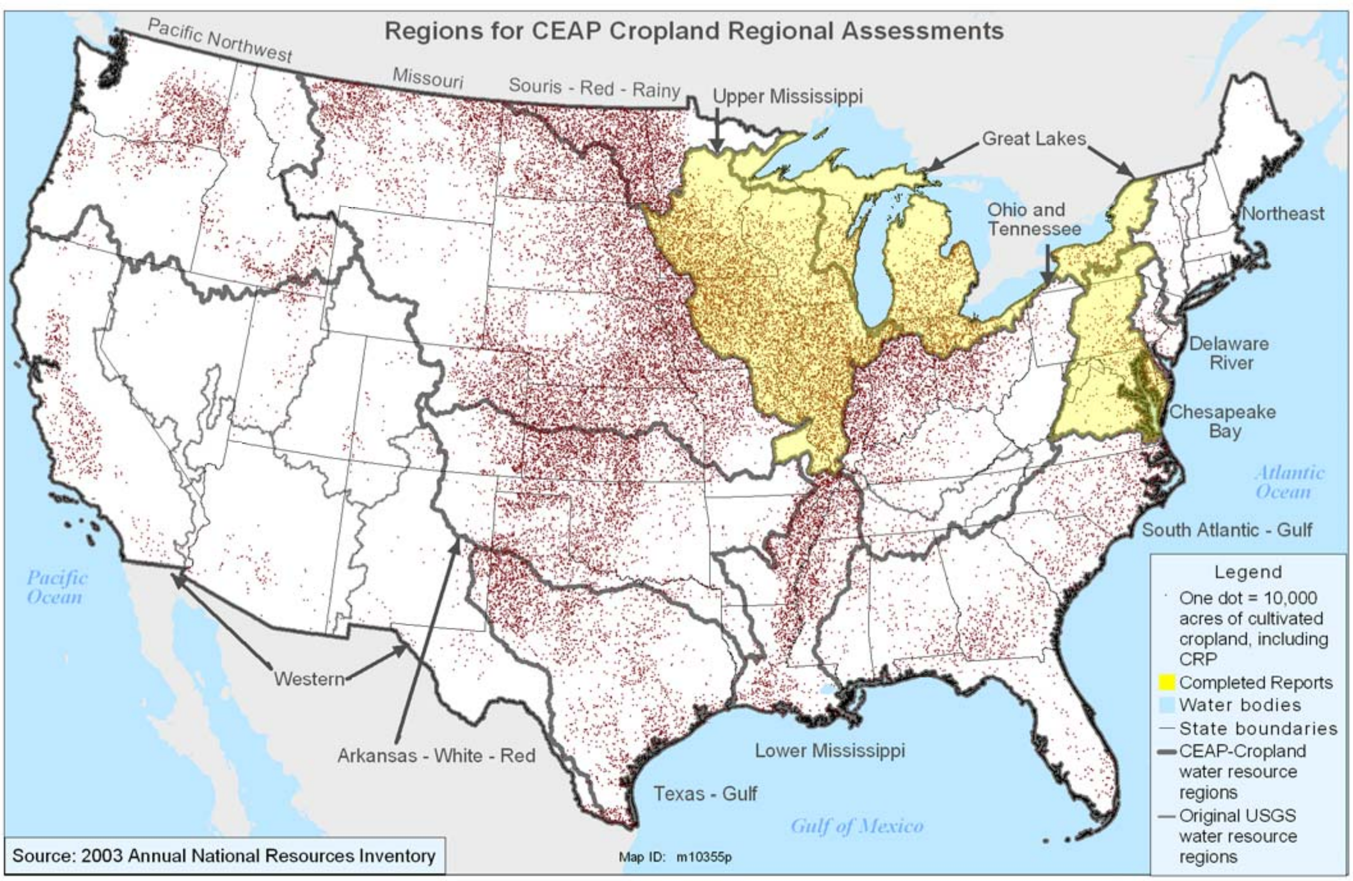
The United States Department of Agriculture has a rich tradition of working with farmers and ranchers to enhance agricultural productivity and environmental protection. Conservation pioneer Hugh Hammond Bennett worked tirelessly to establish a nationwide Soil Conservation Service along with a system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

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



Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Great Lakes Region

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/technical/nri/ceap. (Click on "Cropland" and then click on "documentation reports and associated publications.") Included are the following reports that provide details on the modeling and databases used in this study:

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

Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Great Lakes Region

Executive Summary

Agriculture in the Great Lakes Region

The Great Lakes drainage covers about 296,000 square miles—about 40 percent in Ontario, Canada, and 60 percent in the United States. This report covers only the U.S. portion of the Great Lakes drainage, referred to in this report as the Great Lakes Region.

The Great Lakes Region consists of the drainage area within the United States for five lakes and their tributaries—Lake Superior, Lake Michigan, Lake Huron, Lake Erie, and Lake Ontario. The Great Lakes Region covers about 174,000 square miles and includes parts of eight States—nearly all of Michigan, significant parts of New York, Ohio, and Wisconsin, and small parts of Minnesota, Indiana, Illinois, and Pennsylvania. About a third of the area is open water. Excluding water, agricultural land makes up about 37 percent of the land base—24 percent cultivated cropland and 13 percent permanent hayland and grazing land. About 10 percent of the land base is urban land. The remaining land area is primarily forested.

Agriculture plays an important role in the economy of the region. The 2007 Census of Agriculture reported that there were nearly 126,000 farms in the Great Lakes Region and that the value of agricultural sales was about $14.5 billion—about half from crop production and half from livestock production. About 67 percent of the farms primarily raise crops, about 26 percent are primarily livestock operations, and the remaining 7 percent produce a mix of livestock and crops. Most of the farms (71 percent) in 2007 were small operations with less than $50,000 in total farm sales. About 6 percent of the farms had total farm sales greater than $500,000. Corn, soybeans, and hay are the principal crops grown.

Livestock production in the region is dominated by dairy. Livestock operations in the region produced 15 percent of all dairy product sales in the United States in 2007, totaling $4.7 billion in value. Cattle sales ranked second in the region at $1.2 billion, representing 2 percent of the U.S. total.

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

The primary focus of the CEAP Great Lakes Region study is on the 24 percent of the watershed that is cultivated cropland. The study was designed to—

- quantify the effects of conservation practices commonly used on cultivated cropland in the Great Lakes Region 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 on cultivated cropland. 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 that were 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 data 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. The sample size of the farmer survey—18,700 sample points nationally with 1,418 sample points in the Great Lakes Region—is sufficient for reliable and defensible reporting at the regional scale with some reporting for large watersheds within the region, but is generally insufficient for assessments of smaller areas within the region.

Voluntary, Incentives-Based Conservation Approaches Are Achieving Results

The study shows that farmers in the Great Lakes Region have made significant progress in reducing sediment, nutrient, and pesticide losses from farm fields through conservation practice adoption.

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 94 percent of the acres.

- Structural practices for controlling water erosion are in use on 26 percent of cropped acres. Seventeen percent of cropped acres are designated as highly erodible land; structural practices designed to control water erosion are in use on 37 percent of these acres.
- Reduced tillage is common in the region; 82 percent of the cropped acres meet criteria for either no-till (32 percent) or mulch till (50 percent). All but 9 percent of the acres had evidence of some kind of reduced tillage on at least one crop in the rotation.

The farmer survey also found that most acres have evidence of some nitrogen or phosphorus management.

- Appropriate *timing* of nitrogen and phosphorus applications is in use on about 69 percent of the acres for all crops in the rotation.
- Appropriate *rates* of nitrogen application are in use on about 40 percent of the acres for all crops in the rotation, and appropriate *rates* of phosphorus application are in use on about 45 percent of the acres for all crops in the rotation.

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, including nearly all of the acres receiving manure.

- Appropriate nitrogen application rates, timing of application, and application method for all crops during every year of production are in use on only about 18 percent of cropped acres.
- Appropriate phosphorus management practices (appropriate rate, timing, and method) are in use on 29 percent of the acres on all crops during every year of production.
- Only about 12 percent of cropped acres meet full nutrient management criteria for *both* phosphorus and nitrogen management.

About 46 percent of cropped acres are gaining soil organic carbon. An additional 25 percent of cropped acres are considered to be “maintaining” soil organic carbon (average annual loss less than 100 pounds per acre). Overall, 71 percent of cropped acres are maintaining or enhancing soil organic carbon.

Land in long-term conserving cover, as represented by enrollment in the Conservation Reserve Program (CRP) General Signup, consists of 593,000 acres in the region, of which 40 percent is highly erodible land.

Conservation Accomplishments

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

- reduced wind erosion by 44 percent;
- reduced waterborne sediment loss from fields by 47 percent;
- reduced nitrogen lost with surface runoff (attached to sediment and in solution) by 43 percent;
- reduced nitrogen loss in subsurface flows by 30 percent;
- reduced total phosphorus loss (all loss pathways) from fields by 39 percent;
- reduced pesticide loss from fields to surface water, resulting in a 26-percent reduction in edge-of-field pesticide risk (all pesticides combined) for humans and a 27-percent reduction for aquatic ecosystems; and
- increased the percentage of cropped acres gaining soil organic carbon from 27 to 46.

For land in long-term conserving cover (593,000 acres), soil erosion and sediment loss have been almost completely eliminated. Compared to a cropped condition without conservation practices, average annual total nitrogen loss has been reduced by 77 percent, average annual total phosphorus loss has been reduced by 88 percent, and the annual change in soil organic carbon has been increased by an average of 326 pounds per acre per year.

Reductions in field-level losses due to conservation practices, including land in long-term conserving cover, are expected to improve water quality in streams and rivers in the region. Edge-of-field losses of sediment, nitrogen, phosphorus, and the pesticide atrazine were incorporated into a national water quality model to estimate the extent to which conservation practices have reduced amounts of these contaminants delivered to rivers and streams throughout the region. Transport of sediment, nutrients, and pesticides from farm fields to streams and rivers involves a variety of processes and time-lags, and not all of the potential pollutants leaving fields contribute to instream loads.

The model simulations showed that conservation practices in use during the period 2003–06 have reduced average annual loads delivered to rivers and streams within the basin, compared to a no-practice scenario, by 50 percent for sediment, 37 percent for nitrogen, 36 percent for phosphorus, and 24 percent for atrazine. The national water quality model also provided estimates of reductions in ***instream loads*** due to conservation practice use. *When considered along with loads from all other sources*, conservation practices in use on cultivated cropland in 2003–06 have reduced total instream loads delivered to the Lakes by—

- 12 percent for sediment,
- 21 percent for nitrogen
- 20 percent for phosphorus, and
- 23 percent for atrazine.

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

The assessment of conservation treatment needs presented in this study identifies significant opportunities to further reduce contaminant losses from farm fields. The study found that 19 percent of cropped acres (2.84 million 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. An additional 34 percent of cropped acres (5.04 million acres) have a **moderate** need for additional conservation treatment. The remaining cropped acres (6.92 million acres) have a **low** need for additional treatment, and are considered to be adequately treated.

Model simulations show that adoption of additional erosion control and nutrient management practices on the 7.9 million acres with a **high** or **moderate** treatment need, compared to the 2003–06 baseline, would further reduce edge-of-field sediment loss by 64 percent, losses of nitrogen with surface runoff by 42 percent, losses of nitrogen in subsurface flows by 38 percent, and losses of phosphorus (sediment-attached and soluble) by 41 percent. These field-level reductions, in turn, would further reduce ***instream loads.*** Relative to the 2003–06 baseline, this level of additional conservation treatment would reduce total ***instream loads*** *delivered to the Lakes from all sources* by—

- 9 percent for sediment,
- 16 percent for nitrogen,
- 15 percent for phosphorus, and
- 11 percent for atrazine.

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, polymer coated products, nitrogen stabilizers, urease inhibitors, and nitrification inhibitors;
- Drainage water management that controls discharge of drainage water and treats contaminants, thereby reducing the levels of nitrogen and soluble phosphorus loss;
- Constructed wetlands receiving surface water runoff 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 Implementation Are Essential

The resource concern with the most widespread need for additional conservation treatment related to cropland in the region is nitrogen loss in subsurface flows. About 16 percent of cropped acres in the region have a **high** need for additional nutrient management to address this concern, and an additional 29 percent have a **moderate** need. Subsurface flows include water that is intercepted by tile drains or drainage ditches, groundwater that contributes to streamflow, and lateral subsurface flow that emerges as surface water runoff, such as natural seeps. Most of the nitrogen lost from fields in subsurface flows is eventually discharged into streams, rivers, and lakes.

Of the 7.9 million acres with either a **high** or **moderate** need for additional conservation treatment—

- 68 percent are under-treated only for nitrogen loss in subsurface flows,
- 8 percent are under-treated only for phosphorus loss, and
- 9 percent are under-treated for both nitrogen loss in subsurface flows and phosphorus loss.

Additional water erosion control is also needed in some parts of the region, primarily in the Lake Michigan drainage and the Lake Ontario drainage. The study found that 4 percent of cropped acres have a **high** need for additional water erosion control in the Great Lakes Region; an additional 2 percent have a **moderate** need. Two percent of cropped acres in the region have a **moderate** need for additional control of wind erosion, primarily in the Lake Huron basin.

The Western Lake Erie drainage, including the Maumee River, has the most under-treated acres—2.3 million acres (48 percent of cropped acres) with either a **high** or **moderate** need for additional treatment, primarily for nitrogen loss in subsurface flows. The Lake Ontario drainage, however, has the highest proportion of cropped acres that are under-treated. About 32 percent of the cropped acres in the Lake Ontario basin have a **high** need for additional treatment, primarily for sediment loss and nutrient loss with surface water runoff. An additional 39 percent of cropped acres in the Lake Ontario basin have a **moderate** need for additional treatment. Under-treated acres in the other Lake basins range from 46 to 56 percent of cropped acres.

The need for additional conservation practices to address excessive phosphorus loss (sediment adsorbed and soluble) from fields is also important but less than for nitrogen—12 percent of cropped acres in the region have a **moderate** need for additional treatment. This is due, in part, to ongoing efforts by farmers in the region to better manage phosphorus use. Scientists working on Great Lakes water quality have shown that phosphorus loads from agriculture continue to be an important contributor to water quality impairment within the region.

The high losses of nitrogen and soluble phosphorus in subsurface flows in the region can be addressed with complete and consistent use of nutrient management—appropriate rate, form, timing, *and* method of application. This is especially important for acres that have or need soil erosion control. 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, re-routing the nitrogen and soluble phosphorus from surface to subsurface loss pathways.

A *comprehensive conservation planning process* is required to identify the appropriate combination of nutrient management techniques and soil erosion control practices needed to simultaneously address soil erosion, nutrient losses in runoff, *and* loss of nitrogen in subsurface flows. 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.

Targeting Enhances Effectiveness and Efficiency

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.

Not all acres provide the same benefit from conservation treatment. The more vulnerable acres, such as highly erodible land and soils prone to leaching, inherently lose more sediment or nutrients; therefore greater benefit can be attained with additional conservation treatment. 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 least treated acres also provide greater benefits from treatment, especially if they are also inherently vulnerable to runoff or leaching. The survey showed that, while most acres benefit from some use of conservation practices, environmentally "risky" management is still used on some acres (such as fall application of commercial fertilizers and manure, surface broadcast applications of commercial fertilizers and manure, and conventional tillage).

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 about twice as much as treatment of acres with a **moderate** conservation treatment need. Even greater efficiencies are realized when acres with either a **high** or **moderate** 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 demonstrated that nitrogen loss in subsurface flows in the Great Lakes region would be reduced by an average of 27 pounds per acre per year on the 2.84 million acres with a **high** need for additional treatment, compared to an average reduction of 14 pounds per acre per year for the 5.04 million acres with a **moderate** need for additional treatment. The reduction in nitrogen loss in subsurface flows would average only 2 pounds per acre per year for treatment of the 6.92 million 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 of the 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, 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 with fewer row crop years, 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 Great Lakes Region

Land Use

The Great Lakes drainage covers about 296,000 square miles—about 40 percent in Ontario, Canada, and 60 percent in the United States. This report covers only the U.S. portion of the Great Lakes drainage, referred to in this report as the Great Lakes Region.

The Great Lakes Region covers about 174,000 square miles and includes parts of eight states—nearly all of Michigan, significant parts of Wisconsin, New York, and Ohio, and small parts of Minnesota, Indiana, Illinois, and Pennsylvania. About a third of the area is open water. Excluding water, agricultural land makes up about 37 percent of the land base—24 percent cultivated cropland and 13 percent permanent hayland and grazing land (table 1 and fig. 1). About 10 percent of the land base is urban land. Wetlands consist of about 15 percent of the land base, and the remaining land area is primarily forested. The major metropolitan areas are Detroit, Michigan; Cleveland, Ohio; and Chicago, Illinois. Overall, 68 percent of the cropped acres in the region are in two of the eight states—Michigan and Ohio. Wisconsin has 14 percent of the cropped acres and the remaining five states together have 18 percent.

Table 1. Distribution of land cover in the Great Lakes Region*

Land use	Acres*	Percent including water	Percent excluding water
Cultivated cropland and land enrolled in the CRP General Signup**	17,817,364	16	24
Hayland not in rotation with crops	2,886,885	3	4
Pastureland not in rotation with crops	2,799,684	3	4
Rangeland--grass	2,344,247	2	3
Rangeland-- brush	1,233,005	1	2
Horticulture	284,526	<1	<1
Forestland			
Deciduous	19,613,334	18	27
Evergreen	4,898,593	4	7
Mixed	2,674,172	2	4
Urban	7,634,794	7	10
Wetlands			
Forested	9,621,864	9	13
Non-Forested	1,243,423	1	2
Barren	292,856	<1	<1
Subtotal	73,344,746	66	100
Water	38,232,732	34	--
Total	111,576,697	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.
**Includes hayland and pastureland in rotation with crops.

Agriculture

The 2007 Census of Agriculture reported 125,715 farms in the Great Lakes Region, about 6 percent of the total number of farms in the United States (table 2). Farmland in the Great Lakes Region makes up about 3 percent of all farmland in the nation. According to the 2007 Census of Agriculture, the value of Great Lakes Region agricultural sales in 2007 was about $14.5 billion—about half from crops and half from livestock. About 67 percent of Great Lakes Region farms primarily raise crops, about 26 percent are primarily livestock operations, and the remaining 7 percent produce a mix of livestock and crops (table 3).

Most of the farms (71 percent) in 2007 were small operations with less than $50,000 in total farm sales (table 3). About 36,000 farms had total agricultural sales greater than $50,000, of which about 8,000 farms (6 percent) had total farm sales greater than $500,000. Forty-three percent of the farms in the Great Lakes Region are smaller than 50 acres, and 48 percent are between 50 and 500 acres. About 9 percent of the farms (10797 farms) have more than 500 acres (table 3).

Crop production

The Great Lakes Region accounts for about 5 percent of all U.S. crop sales (table 2). Corn and soybean are the principal crops grown. Wheat and hay are important secondary crops in terms of acres harvested. Farmers in the region produced 6 percent of the corn harvested for grain in the United States in 2007—over 700 million bushels—on about 5.4 million acres. Hay, grass silage, haylage, and greenchop were harvested on 3.3 million acres. Farms in the region also produced 7 percent of the national soybean crop (190 million bushels) on 4.5 million acres.

Commercial fertilizers and pesticides are widely used on agricultural land in the region (table 2). In 2007, 13 million acres of cropland were fertilized, 11 million acres of cropland and pasture were treated with chemicals for weed control, and 3.7 million acres of hay and cropland were treated for insect control. About 2.3 million acres had manure applied in 2007. Irrigation was used on about 700,000 acres to supplement rainfall during dry periods.

Livestock operations

Dairy dominates livestock production in the region. Livestock operations in the region produced 15 percent of all dairy product sales in the United States in 2007, totaling $4.7 billion in value (table 2). Cattle sales ranked second in the region at $1.2 billion, representing 2 percent of the U.S. total.

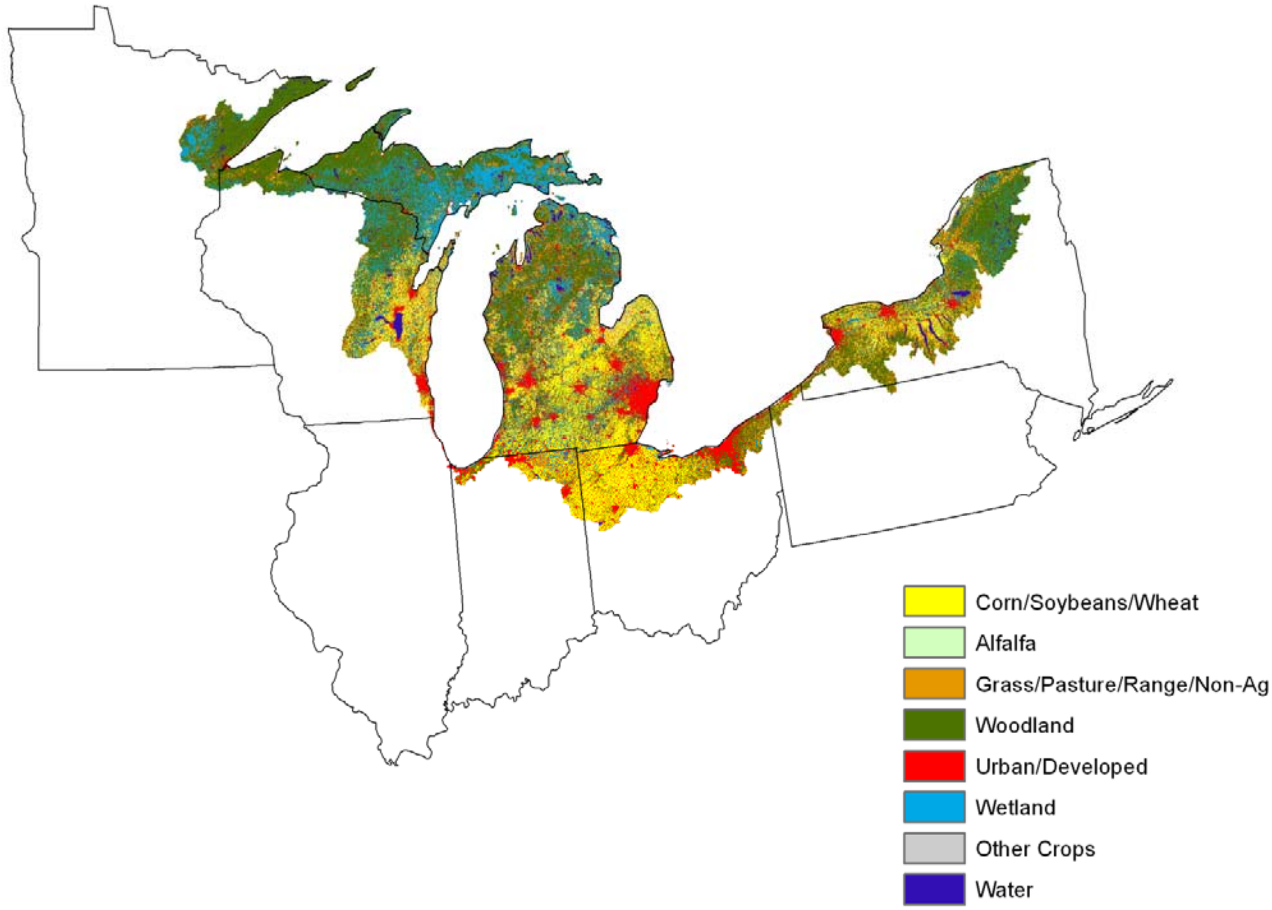
Although about half of the farms in the Great Lakes Region (61,721 farms) reported livestock sales in 2007, the majority are small operations. More than half of these farms had fewer than 30 animal units on the farm; a small number of these had specialty livestock such as rabbits, pheasants, mink, or deer (table 3). (An animal unit is 1,000 pounds of live animal weight.) Pastured livestock (cattle, horses, sheep, or goats) predominate on about 10,516 farms.

Table 2. Profile of farms in the Great Lakes Region, 2007

Characteristic	Value	Percent of national total
Number of farms	125,715	6
Acres on farms	23,682,553	3
Average acres per farm	188	
Cropland harvested, acres	16,556,955	5
Cropland used for pasture, acres	643,430	2
Cropland on which all crops failed, acres	143,795	2
Cropland in summer fallow, acres	107,366	<1
Cropland idle or used for cover crops, acres	1,019,658	3
Woodland pastured, acres	272,238	1
Woodland not pastured, acres	2,556,266	5
Permanent pasture and rangeland, acres	918,931	<1
Other land on farms, acres	1,463,914	5
Principal crops grown		
Field corn for grain harvested, acres	5,397,512	6
Field corn for silage harvested, acres	958,018	16
Soybeans harvested, acres	4,477,251	7
Wheat harvested, sum acres	1,235,795	2
Alfalfa hay harvested, acres	1,500,591	7
Grass silage, haylage, and greenchop harvested, acres	939,467	28
Tame and wild hay harvested, acres	824,409	2
Irrigated harvested land, acres	693,873	1
Irrigated pastureland or rangeland, acres	6,661	<1
Cropland fertilized, acres	13,111,655	5
Pastureland fertilized, acres	131,289	1
Land treated for insects on hay or other crops, acres	3,668,305	4
Land treated for nematodes in crops, acres	262,525	3
Land treated for diseases in crops and orchards, acres	760,205	3
Land treated for weeds in crops and pasture, acres	11,110,423	5
Crops on which chemicals for defoliation applied, acres	195,166	2
Acres on which manure was applied	2,286,544	10
Total grains and oilseeds sales, million dollars	4,160,467,168	5
Total fruit and berry sales, million dollars	669,913,585	4
Total vegetable, melons sales, million dollars	811,875,974	6
Total nursery, greenhouse, and floriculture sales, million dollars	1,059,980,268	6
Total hay and other crop sales, million dollars	411,167,413	2
Total crop sales, million dollars	7,113,404,408	5
Total dairy sales, million dollars	4,735,501,846	15
Total hog and pigs sales, million dollars	655,913,607	4
Total poultry and eggs sales, million dollars	585,325,686	2
Total cattle sales, million dollars	1,213,806,442	2
Total sheep, goats, and their products sales, million dollars	18,275,812	3
Total horses, ponies, and mules sales, million dollars	50,637,353	2
Total other livestock sales, million dollars	121,906,244	5
Total livestock sales, million dollars	7,381,366,990	5
Animal units on farms		
All livestock types	3,557,593	3
Swine	368,193	4
Dairy cows	1,727,618	14
Fattened cattle	227,488	2
Other cattle, horses, sheep, goats	1,075,441	2
Chickens, turkeys, and ducks	135,106	2
Other livestock	23,747	6

Source: 2007 Census of Agriculture, National Agricultural Statistics Service, USDA
Note: Information in the Census of Agriculture was used to estimate animal units using methods and assumptions described in USDA-NRCS (2003).

Figure 1. Land cover in the Great Lakes Region



Source: National Agricultural Statistics Service (NASS 2007).

Table 3. Characteristics of farms in the Great Lakes Region, 2007

	Number of farms	Percent of farms in Great Lakes Region
Farming primary occupation	57,188	45
Farm size:		
<50 acres	54,003	43
50–500 acres	60,915	48
500–2,000 acres	9,670	8
>2,000 acres	1,127	1
Farm sales:		
<$10,000	63,442	50
$10,000–50,000	25,948	21
$50,000–250,000	20,740	16
$250,000–500,000	7,439	6
>$500,000	8,146	6
Farm type:		
Crop sales make up more than 75% of farm sales	83,892	67
Livestock sales make up more than 75% of farm sales	32,740	26
Mixed crop and livestock sales	9,083	7
Farms with no livestock sales	63,994	51
Farms with few livestock or specialty livestock types	34,891	28
Farms with pastured livestock and few other livestock types	10,516	8
Farms with animal feeding operations (AFOs)*	16,314	13

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.

About 16,314 farms (13 percent) could be defined as animal feeding operations (AFOs). AFOs are livestock operations typically with confined poultry, swine, or cattle. The bulk of these are relatively small operations. Only about 2,100 of the livestock operations (13 percent of the AFOs) are relatively large, with livestock numbers in 2007 above the EPA minimum threshold for a small concentrated animal feeding operation (CAFO).

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 code, which is further divided into 4-digit subregions and then into 8-digit watersheds, or Hydrologic Unit Codes (HUCs). The Great Lakes Region is represented by 15 subregions.

The percent of cultivated cropland in each of the 15 subregions within the Great Lakes Region is shown in figure 2 and in table 4. The highest concentration of cultivated cropland, 72.7 percent, is in the Western Lake Erie subregion (subregion code 0410). The Southeastern Lake Michigan subregion (subregion code 0405) has about 41 percent of its land base in cultivated cropland. The remaining subregions have 31 percent or less of the area in cultivated cropland, including five subregions where cropped acres represent less than 5 percent of the area.

About 78 percent of the cultivated cropland in the region is found in only four of the 15 subregions—Western Lake Erie subregion (code 0410), Southeastern Lake Michigan (code 0405), Northwestern Lake Michigan (code 0403), and Southwestern Lake Huron (code 0408). The remaining subregions each have less than 4 percent of the region's cultivated cropland. The Western Lake Superior and Southern Lake Superior subregions (codes 0401 and 0402) have negligible amounts of cultivated cropland.

Figure 2. Percent cultivated cropland, including land in long-term conserving cover, for the 15 subregions in the Great Lakes Region

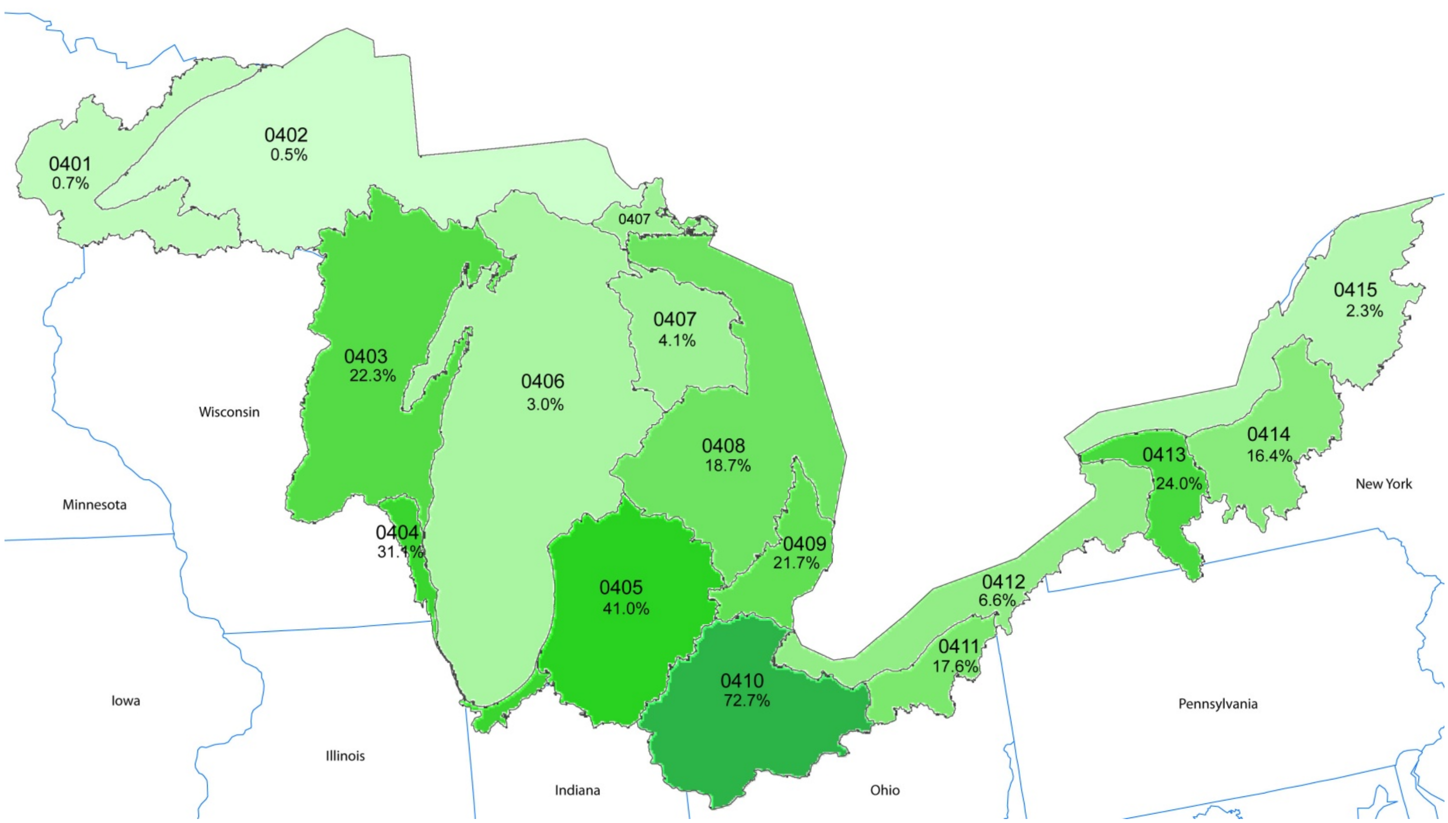


Table 4. Cultivated cropland use in the 15 subregions in the Great Lakes Region

Sub-region code	Subregion name	Total area (acres)	Cultivated cropland (acres)*	Percent cultivated cropland in subregion	Percent of cultivated cropland in Great Lakes Region	Percent of cultivated cropland acres in long-term conserving cover
0401	Western Lake Superior	5,840,784	41,781	0.7	0.2	<0.1
0402	Southern Lake Superior	15,657,228	76,658	0.5	0.4	8.5
0403	Northwestern Lake Michigan	11,975,401	2,671,032	22.3	15.0	4.4
0404	Southwestern Lake Michigan	1,279,022	398,191	31.1	2.2	3.2
0405	Southeastern Lake Michigan	8,249,662	3,383,378	41.0	19.0	3.9
0406	Northeastern Lake Michigan	21,587,090	657,189	3.0	3.7	1.0
0407	Northwestern Lake Huron	4,479,329	182,605	4.1	1.0	<0.1
0408	Southwestern Lake Huron	11,671,756	2,188,360	18.7	12.3	4.9
0409	St. Clair, Detroit, Clinton, Huron Rivers	2,529,892	550,015	21.7	3.1	3.2
0410	Western Lake Erie	7,666,662	5,575,745	72.7	31.3	4.9
0411	Southern Lake Erie	1,948,389	342,907	17.6	1.9	1.7
0412	Eastern Lake Erie	5,043,429	331,578	6.6	1.9	2.8
0413	Southwestern Lake Ontario	2,284,209	548,922	24.0	3.1	2.6
0414	Southeastern Lake Ontario	4,307,253	706,017	16.4	4.0	1.3
0415	Northeastern Lake Ontario	7,056,592	162,984	2.3	0.9	<0.1
	Total	111,576,697	17,817,364	16.0	100.0	4.0

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

Chapter 2
Overview of Sampling and Modeling Approach

Scope of Study

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

- Evaluates the extent of conservation practice use in the region 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.

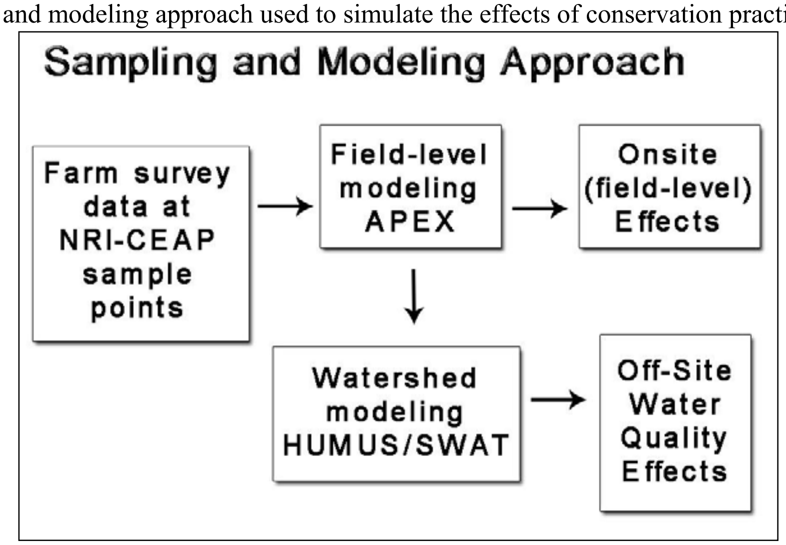
For purposes of this report, cultivated cropland includes land in row crops or close-grown crops, hay and pasture in rotation with row crops and close-grown crops (such as wheat and other small grain crops), and land in long-term conserving cover. Cultivated cropland does not include agricultural land that has been in hay, pasture, or horticulture for 4 or more consecutive years. Acres enrolled in the General Signup of the Conservation Reserve Program (CRP) were used to represent cultivated cropland currently in long-term conserving cover.

Sampling and Modeling Approach

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

- A subset of 1,418 National Resources Inventory (NRI) sample points provides a statistical sample that represents the diversity of soils and other conditions for cropped acres in the Great Lakes Region. The sample also includes 404 additional NRI sample points designated as CRP acres to represent land in long-term conserving cover. NRI sample points are linked to NRCS Soil Survey databases and were linked spatially to climate databases for this study.
- A farmer survey—the NRI-CEAP Cropland Survey—was conducted at these sample points during the period 2003–06 to determine what conservation practices were in use and to collect information on farming practices.
- The field-level effects of the conservation practices were assessed using a field-scale physical process model—the Agricultural Policy Environmental Extender (APEX)—which simulates the day-to-day farming activities, wind and water erosion, loss or gain of soil organic carbon, and edge-of-field losses of soil, nutrients, and pesticides.
- A watershed model and system of databases—the Hydrologic Unit Model for the United States (HUMUS)—was used to simulate how reductions of field losses have reduced instream concentrations and loadings of sediment, nutrients, and pesticides within the Great Lakes Region. The SWAT model (Soil and Water Assessment Tool) was used to simulate nonpoint source loadings from land uses other than cropland and to route instream loads from one watershed to another.

Figure 3. Statistical sampling and modeling approach used to simulate the effects of conservation practices



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

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

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

The approach captures the diversity of land use, soils, climate, and topography from the NRI; accounts for site-specific farming activities; estimates the loss of materials at the field scale where the science is most developed; and provides a statistical basis for aggregating results to the national and regional levels.[2]

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

The NRI and the CEAP Sample

The approach is an extension of the NRI, a longitudinal, scientifically-based survey designed to gauge natural resource status, conditions, and trends on the Nation's non-Federal land (Goebel 1998; USDA-NRCS 2002). NRCS has previously used the NRI for modeling to address issues related to natural resources and agriculture (Goebel and Kellogg 2002). The NRI sampling design implemented in 1982 provided a stratified, two-stage, unequal probability area sample of the entire country (Goebel and Baker 1987; Nusser and Goebel 1997). Nominally square areas/segments were selected within geographical strata on a county-by-county basis; specific point locations were selected within each selected segment. The segments ranged in size from 40 to 640 acres but were typically half-mile square areas, and most segments contained three sample points. At each sample point, information is collected on nearly 200 attributes; some items are also collected for the entire segment. The sampling rates for the segments were variable, typically from 2 to 6 percent in agricultural strata and much lower in remote nonagricultural areas. The 1997 NRI Foundation Sample contained about 300,000 sample segments and about 800,000 sample points.

NRCS made several significant changes to the NRI program over the past 10 years, including transitioning from a 5-year periodic survey to an annual survey. The NRI's annual design is a *supplemented panel design.* A *core panel* of 41,000

[1] 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. 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.

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

segments is sampled each year, and *rotation (supplemental) panels* of 31,000 segments each vary by inventory year and allow an inventory to focus on an emerging issue. The core panel and the various supplemental panels are unequal probability subsamples from the 1997 NRI Foundation Sample.[3]

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 NRI-CEAP usable sample consists of about 18,700 NRI points representing cropped acres, and about 13,000 NRI points representing land enrolled in the General Signup of the CRP.

The Great Lakes Region portion of the NRI-CEAP sample consists of 1,418 sample points representing 14.8 million cropped acres and 425 sample points representing 593,000 acres of cultivated cropland in long-term conserving cover. Acres reported using the CEAP sample are "estimated" acres because of the uncertainty associated with the statistical sample. Margins of error for estimated cropped acres used in this report are provided in appendix A.

For example, the 95-percent confidence interval for the estimate of 14,803,500 cropped acres in the Great Lakes region has a lower bound of 14,250,587 acres and an upper bound of 15,356,413 acres.

Table 5 provides a breakdown of sample sizes for cropped acres in the Great Lakes Region by cropping system and by subregion. Corn-soybean rotations (including corn-soybean rotations with close grown crops) are the dominant cropping systems in the region, representing 53 percent of cropped acres. About 86 percent of the cropped acres include corn or soybeans or both in the crop rotation.

[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 "NRI-CEAP Cropland Survey Design and Statistical Documentation," available at http://www.nrcs.usda.gov/technical/nri/ceap.

The CEAP sample was designed to allow reporting of results at the subregion (4-digit HUC) level in most cases. The acreage weights were derived so as to approximate total cropped acres by subregion as estimated by the full 2003 NRI. The sample size is too small, in most cases, for reliable and defensible reporting of results for areas below the subregion level. Sample sizes for some subregions were too small to reliably report cropped acres; estimates for six basins were used for reporting, combining subregions as shown in table 5.

The NRI-CEAP Cropland Survey

A farmer survey—the NRI-CEAP Cropland Survey—was conducted to obtain the additional information needed for modeling the 1,418 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.

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

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

Table 5. Estimated cropped acres based on the NRI-CEAP sample in the Great Lakes Region

Breakdown		Number of CEAP samples	Estimated acres	Percent of cropped acres
By Cropping System				
Corn-soybean only		627	5,894,702	40
Corn-soybean with close grown crops		185	1,890,721	13
Corn only		137	1,556,955	11
Soybean only		82	714,208	5
Soybean-wheat only		105	1,048,777	7
Corn and close grown crops		44	484,652	3
Vegetable or tobacco with or without other crops		73	1,091,770	7
Hay-crop mix (rotations include corn or soybean)		124	1,628,555	11
Remaining mix of crops		41	493,160	3
	Total	1,418	14,803,500	100
By Subregion				
Lake Superior basin (subregion codes 0401 and 0402)		1	*	<1
Western Lake Michigan basin				
Northwestern Lake Michigan-Fox River (subregion code 0403)		170	1,953,000	13
Southwestern Lake Michigan (subregion code 0404)		56	350,100	2
Eastern Lake Michigan basin				
Southeastern Lake Michigan (subregion code 0405)		338	3,145,900	21
Northeastern Lake Michigan (subregion code 0406)		24	320,000	2
Lake Huron basin				
Northwestern Lake Huron (subregion code 0407)		2	*	<1
Southwestern Lake Huron-Saginaw River (subregion code 0408)		123	2,017,300	14
Lake Erie basin				
St. Clair-Detroit-Clinton-Huron River (subregion code 0409)		52	434,700	3
Western Lake Erie (subregion code 0410)		492	4,801,700	32
Southern Lake Erie (subregion code 0411)		33	239,800	2
Eastern Lake Erie (subregion code 0412)		15	183,400	1
Lake Ontario				
Southwestern Lake Ontario (subregion code 0413)		38	472,300	3
Southestern Lake Ontario-Oswego River (subregion code 0414)		67	710,800	5
North Eastern Lake Ontario-St. Lawrence River (subregion code 0415)		7	*	<1
	Total	1,418	14,803,500	100

Note: Estimates are from the 2003 NRI and the NRI-CEAP Cropland Survey. Cultivated cropland acres in this table differ slightly from estimates presented in tables 1 and 4 because of differences in data sources and estimation procedures.
* Sample size is too small to reliably estimate acreage.

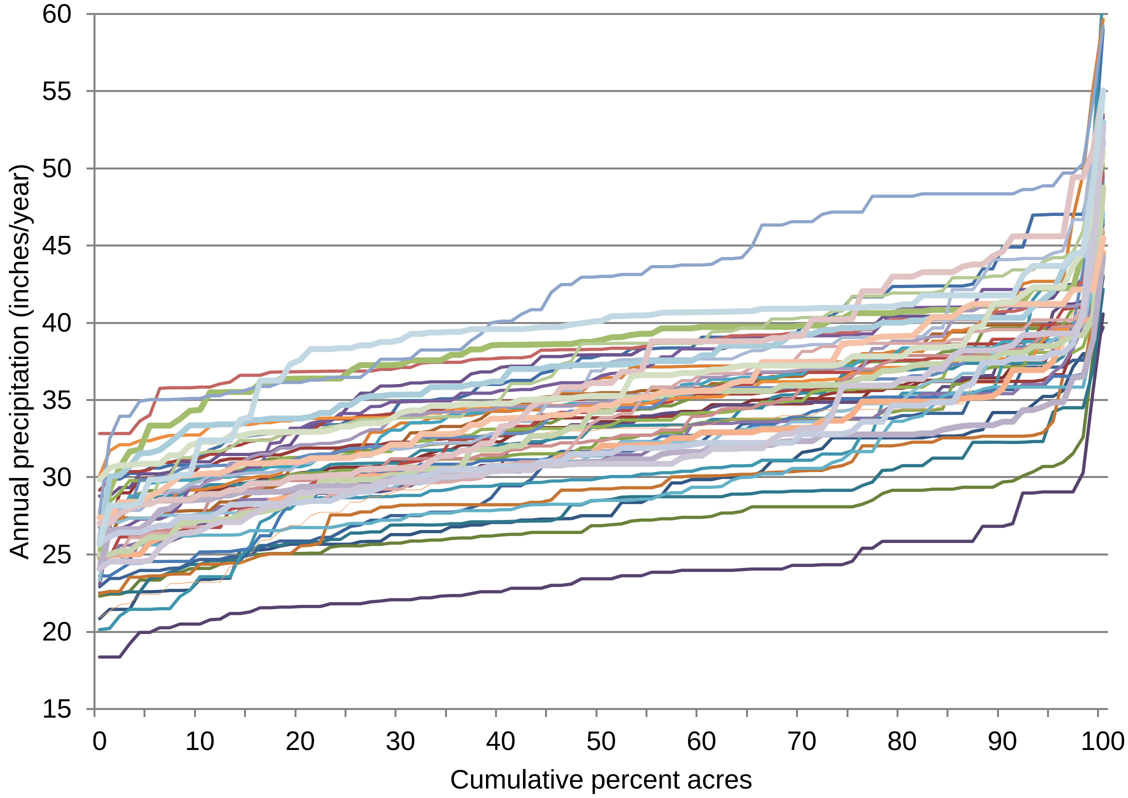
Simulating the Effects of Weather

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

Annual precipitation over the 47-year simulation averaged about 33.6 inches for cropped acres in this region, ranging from 30 inches per year for the Lake Huron basin to 36 inches per year for the Lake Ontario basin. Annual precipitation varied substantially in the model simulations, both within the region and from year to year, as shown in figures 5 and 6. Each curve in figure 5 shows how annual precipitation varied over the region in one of the 47 years. The family of curves shows the variability from year to year. The top curve shown is for the year 1990, the wettest year in this region during the 47 years. The average annual precipitation amount (representing all cropped acres) ranged from 24 inches in 1963 to 42 inches in 1990 over the 47 years (fig. 6)

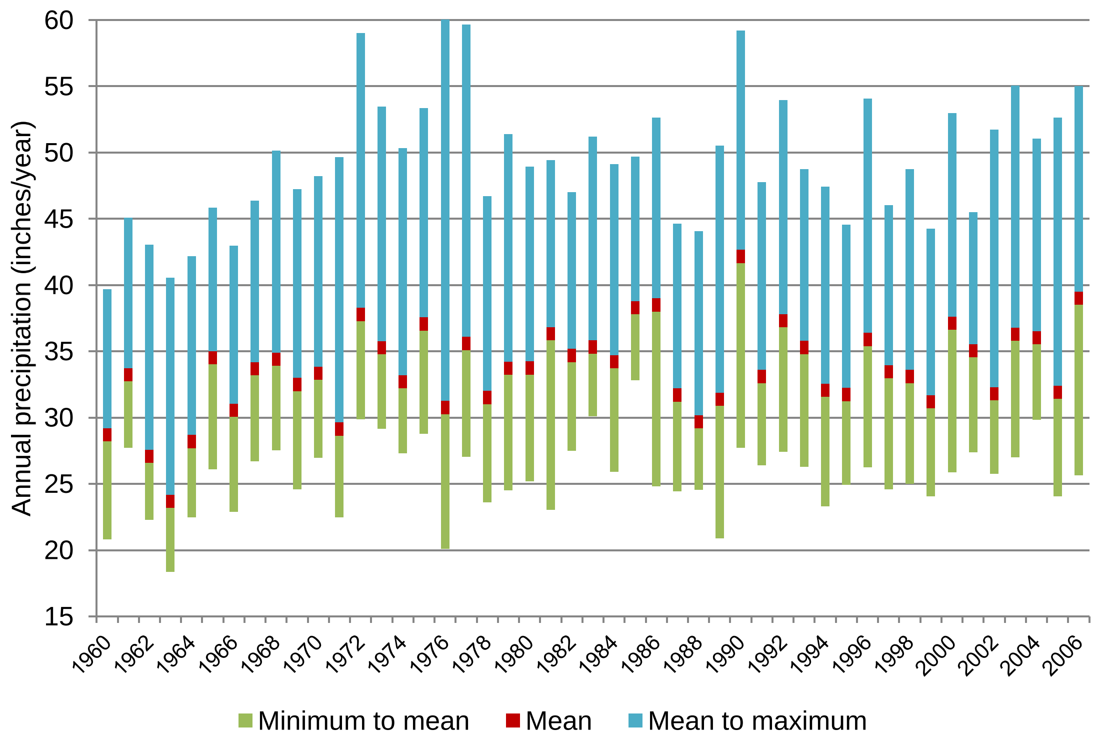
Throughout most of this report model results are presented in terms of the 47-year averages where weather is the only input variable that changes year to year. Since we used the cropping patterns and practices for the 2003–06 period, we did not simulate *actual* loses for each of these years. Rather,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

Figure 5. Cumulative distributions of annual precipitation used in the model simulations for cropped acres in the Great Lakes Region



Note:. Each of the 47 curves shown above represents a single year of data and shows how annual precipitation varies over the region in that year, starting with the driest acres within the region and increasing to the wettest acres for each year. The family of curves shows how annual precipitation varies from year to year. Annual precipitation over the 47-year simulation averaged about 33.6 inches for cropped acres.

Figure 6. Mean, minimum, and maximum levels of annual precipitation used in the model simulations for cropped acres in the Great Lakes Region



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

This study assesses the use and effectiveness of conservation practices in the Great Lakes Region for the period 2003–06 to determine the baseline conservation condition for the region. The baseline conservation condition provides a benchmark for estimating the effects of existing conservation practices as well as projecting the likely effects of alternative conservation treatment. Conservation practices that were evaluated include structural practices, annual practices, and long-term conserving cover.

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

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

Annual conservation practices 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, and reduce the availability of sediment, nutrients, and pesticides for transport by wind or water. They include—

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

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

Historical Context for Conservation Practice Use

The use of conservation practices in the Great Lakes Region closely reflects the history of Federal conservation programs and technical assistance. In the beginning the focus was almost entirely on reducing soil erosion and preserving the soil's productive capacity. In the 1930s and 1940s, Hugh Hammond Bennett, the founder and first chief of the Soil Conservation Service (now Natural Resources Conservation Service) instilled in the national ethic the need to treat every acre to its potential by controlling soil erosion and water runoff. Land shaping structural practices (such as terraces, contour farming, and 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. The Conservation Reserve Program was established to enroll the most erodible cropland acres in multi-year contracts to plant acres in long-term conserving cover.

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

Summary of Practice Use

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

- Structural practices for controlling water erosion are in use on 26 percent of cropped acres. On the 17 percent of the acres designated as highly erodible land, structural practices designed to control water erosion are in use on 37 percent of those acres.
- Reduced tillage is common in the region; 82 percent of the cropped acres meet criteria for either no-till (32 percent) or mulch till (50 percent). All but 9 percent of the acres had evidence of some kind of reduced tillage on at least one crop.
- About 46 percent of cropped acres are gaining soil organic carbon.
- Producers use either residue and tillage management practices or structural practices, or both, on 94 percent of the acres.
- While most acres have evidence of some nitrogen or phosphorus management, the majority of the acres in the

region lack consistent use of appropriate rates, timing, *and* method of application on each crop in every year of production, including nearly all of the acres receiving manure.
  - Appropriate timing of nitrogen applications is in use on about 69 percent of the acres for all crops in the rotation.
  - About 40 percent of cropped acres meet criteria for appropriate nitrogen application rates for all crops in the rotation.
  - Appropriate nitrogen application rates, timing of application, and application method for all crops during every year of production, however, are in use on only about 18 percent of cropped acres.
  - Good phosphorus management practices (appropriate rate, timing, and method) are in use on 29 percent of the acres on all crops during every year of production.
  - Only about 12 percent of cropped acres meet full nutrient management criteria for *both* phosphorus and nitrogen management, including acres not receiving nutrient applications.
- During the 2003–06 period of data collection cover crops were used on about 1 percent of the acres in the region.
- An Integrated Pest Management (IPM) indicator showed that only about 6 percent of the acres were being managed at a relatively high level of IPM.
- Land in long-term conserving cover, as represented by enrollment in the CRP General Signup, consists of about 593,000 acres in the region, of which 40 percent is highly erodible land.

Structural Conservation Practices

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

1. **The NRI-CEAP Cropland Survey** included questions about the presence of 12 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 9 percent of the cropped acres in the region; including 15 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 12 percent of the cropped acres have one or more of these practices, including 22 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 12 percent of all cropped acres in the region (table 6).

Overall, about 26 percent of the cropped acres in the Great Lakes Region are treated with one or more water erosion control structural practices (table 6). The treated percentage for highly erodible land acres is higher—37 percent.

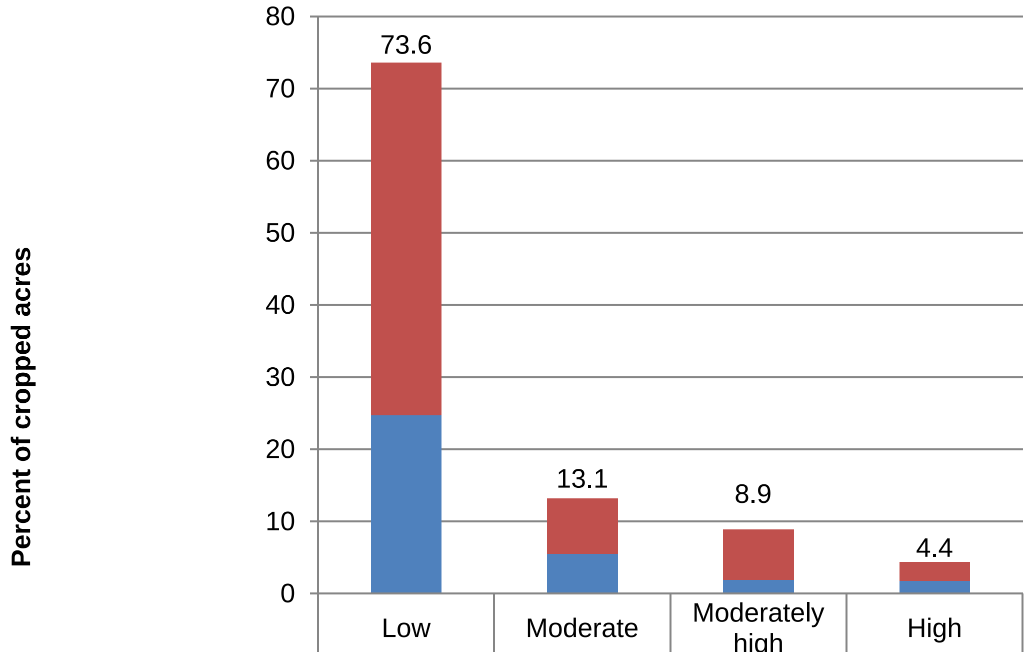
At each sample point, structural conservation practices for water erosion control were classified as either a high, moderately high, moderate, or low level of treatment according to criteria presented in figure 7. About 4 percent of cropped acres in the region have a high level of treatment (combination of edge-of-field buffering or filtering and at least one in-field structural practice). About 74 percent of the acres do not have structural practices for water erosion control; however, two-thirds of these acres have slopes less than 2 percent, some of which may not need to be treated with structural practices. (These treatment levels are combined with soil risk classes to estimate acres that appear to be under-treated for water erosion control in chapter 5.)

Table 6. Structural conservation practices in use for the baseline conservation condition, Great Lakes Region

Structural practice category	Conservation practice in use	Percent of non-HEL	Percent of HEL	Percent of cropped acres
Overland flow control practices	Terraces, contour buffer strips, contour farming, stripcropping, contour stripcropping, field border, in-field vegetative barriers	8	15	9
Concentrated flow control practices	Grassed waterways, grade stabilization structures, diversions, other structures for water control	10	22	12
Edge-of-field buffering and filtering practices	Riparian forest buffers, riparian herbaceous buffers, filter strips	12	11	12
One or more water erosion control practices	Overland flow, concentrated flow, or edge-of-field practice	24	37	26
Wind erosion control practices	Windbreaks/shelterbelts, cross wind trap strips, herbaceous windbreak, hedgerow planting	4	7	4

Note: About 17 percent of cropped acres in the Great Lakes Region are highly erodible land (HEL). Soils are classified as HEL if they have an erodibility index (EI) score of 8 or higher. A numerical expression of the potential of a soil to erode, EI considers the physical and chemical properties of the soil and climatic conditions where it is located. The higher the index, the greater the investment needed to maintain the sustainability of the soil resource base if intensively cropped. The Lake Ontario basin has the highest percentage of HEL—31 percent of cropped acres.

Figure 7. Percent of cropped acres at four conservation treatment levels for structural practices, baseline conservation condition, Great Lakes Region



	Low	Moderate	Moderately high	High
Slope 2 percent or less	48.9	7.6	7.0	2.6
Slope greater than 2 percent	24.7	5.5	1.9	1.8

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.

Note: See appendix B, table B3, for a breakdown of conservation treatment levels by Lake basin.

Wind erosion control practices are designed to reduce the force of the wind on the field. NRCS structural practices for wind erosion control include cross wind ridges, cross wind trap strips, herbaceous wind barriers, and windbreak/shelterbelt establishment. Wind erosion is a resource concern for some acres in this region. About 4 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.

The Soil Tillage Intensity Rating (STIR) (USDA-NRCS 2007) was used to determine the soil disturbance intensity 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, as defined in table 7.

Overall, 82 percent of cropped acres in the Great Lakes Region meet the tillage intensity rating for either no-till or mulch till (table 7). About 32 percent meet the criteria for no-till—21 percent of cropped acres with gains in soil organic carbon and 11 percent with soil organic carbon loss. About 50 percent meet the tillage intensity criteria for mulch till—22 percent of cropped acres with gains in soil organic carbon and 28 percent with soil organic carbon loss. Only 9 percent of the acres are conventionally tilled for all crops in the rotation.

Most of the cropped acres (94 percent) in the Great Lakes Region have some kind of water erosion control practice—either reduced tillage or structural practices or both (table 8). About 22 percent meet tillage intensity for no-till or mulch till *and* have structural practices, including 30 percent of highly erodible land. About 60 percent of cropped acres meet tillage criteria without structural practices in use. Only 6 percent have no water erosion control practices.

Four levels of treatment for residue and tillage management practices were derived according to criteria presented in figure 8. (These treatment levels are combined with soil risk classes to estimate acres that appear to be under-treated for water erosion control in chapter 5.) The high and moderately high treatment levels represent the 43.2 percent of cropped acres that meet tillage intensity criteria for either no-till or mulch till with gains in soil organic carbon. The high treatment level (36 percent of the acres) includes only those acres where the tillage intensity criteria are met for *each* crop in the rotation. The majority of the acres have a moderate level of treatment because soil organic carbon is not being enhanced. Only 7.5 percent of the acres have a low treatment level, consisting of continuous conventional tillage for all crops in the rotation and loss of soil organic carbon.

---

[6] Percent residue cover was not used to determine notill or mulch till because this criterion is not included in the current NRCS practice standard for Residue and Tillage Management.

Table 7. Residue and tillage management practices for the baseline conservation condition, Great Lakes Region

Residue and tillage management practice in use	Percent of non-HEL	Percent of HEL	Percent of all acres
Acres with carbon gain	48	35	46
Average annual tillage intensity for crop rotation meets criteria for no-till*	22	18	21
Average annual tillage intensity for crop rotation meets criteria for mulch till**	24	14	22
Reduced tillage on some crops in rotation but average annual tillage intensity greater than criteria for mulch till	1	2	1
Continuous conventional tillage in every year of crop rotation***	2	1	2
Acres with carbon loss	52	65	54
Average annual tillage intensity for crop rotation meets criteria for no-till*	10	15	11
Average annual tillage intensity for crop rotation meets criteria for mulch till**	28	32	28
Reduced tillage on some crops in rotation but average annual tillage intensity greater than criteria for mulch till	7	8	7
Continuous conventional tillage in every year of crop rotation***	7	10	7
All acres			
Average annual tillage intensity for crop rotation meets criteria for no-till*	32	33	32
Average annual tillage intensity for crop rotation meets criteria for mulch till**	51	46	50
Reduced tillage on some crops in rotation but average annual tillage intensity greater than criteria for mulch till	8	10	9
Continuous conventional tillage in every year of crop rotation***	9	12	9

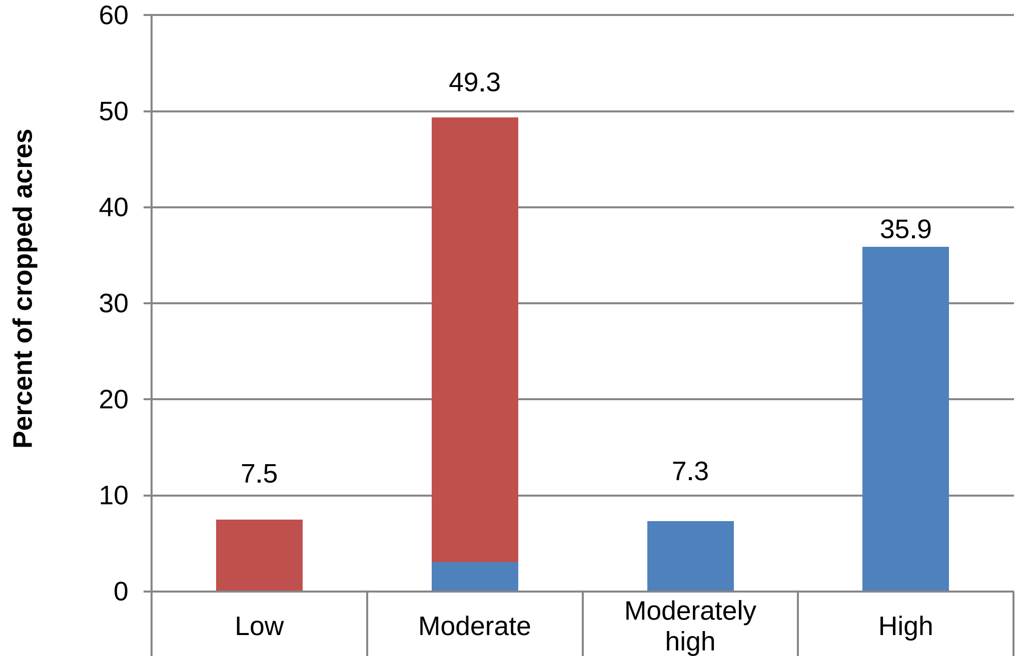
* Average annual Soil Tillage Intensity Rating (STIR) over all crop years in the rotation is less than 30.
** Average annual Soil Tillage Intensity Rating (STIR) over all crop years in the rotation is between 30 and 100.
*** Soil Tillage Intensity Rating (STIR) for every crop year in the rotation is more than 100.
Note: A description of the Soil Tillage Intensity Rating (STIR) can be found at http://stir.nrcs.usda.gov/.
Note: HEL = highly erodible land. About 17 percent of cropped acres in the Great Lakes Region are highly erodible land (HEL).
Note: Percents may not add to totals because of rounding.
Note: Percent residue cover was not used to determine no-till or mulch till.

Table 8. Percent of cropped acres with water erosion control practices for the baseline conservation condition, Great Lakes Region

Conservation treatment	Percent of non-HEL	Percent of HEL	Percent of all cropped acres
No-till or mulch till with carbon gain, no structural practices	33	19	30
No-till or mulch till with carbon loss, no structural practices	30	30	30
Some crops with reduced tillage, no structural practices	7	8	7
Structural practices and no-till or mulch till with carbon gain	13	13	13
Structural practices and no-till or mulch till with carbon loss	8	17	9
Structural practices and some crops with reduced tillage	1	2	1
Structural practices only	3	6	3
No water erosion control treatment	6	6	6
All acres	100	100	100

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

Figure 8. Percent of cropped acres at four conservation treatment levels for residue and tillage management, baseline conservation condition, Great Lakes Region



	Low	Moderate	Moderately high	High
Losing carbon	7.5	46.3	0.0	0.0
Gaining carbon	0.0	3.0	7.3	35.9

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

- **High treatment**: *All crops* meet tillage intensity criteria for either no-till or mulch till and crop rotation is gaining soil organic carbon.
- **Moderately high treatment**: *Average annual* tillage intensity meets criteria for mulch till or no-till and crop rotation is gaining soil organic carbon; some crops in rotation exceed tillage intensity criteria for mulch till.
- **Moderate treatment**: Some crops have reduced tillage but tillage intensity exceeds criteria for mulch till or crop rotation is gaining soil organic carbon and tillage intensity exceeds criteria for mulch till; most acres in this treatment level are losing soil organic carbon.
- **Low treatment**: Continuous conventional tillage and crop rotation is losing soil organic carbon.

Note: See appendix B, table B3, for a breakdown of conservation treatment levels by Lake basin.

The evaluation of conservation practices and associated estimates of conservation treatment needs are based on practice use derived from a farmer survey conducted during the years 2003–06. Since that time, however, States in the Great Lakes Region have continued to work with farmers to enhance conservation practice adoption to reduce nonpoint source pollution contributing to water quality issues. The U.S. Environmental Protection Agency (EPA) and the Natural Resources Conservation Service (NRCS) initiated the Great Lakes Restoration Initiative in 2010, which provided additional technical assistance and conservation program funding for priority watersheds in the Great Lakes Basin to promote voluntary conservation actions by agricultural producers. As a result, some practices may be in wider use within the watershed than the CEAP survey shows for 2003–06.

Conservation Crop Rotation

In the Great Lakes Region, crop rotations that meet NRCS criteria (NRCS practice code 328) occur on about 84 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 hay or a close grown crop in the rotation can have a pronounced effect on long-term average field losses of sediment and nutrients, as well as enhancement of soil quality.

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

Cover Crops

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

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

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

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

In the Great Lakes Region, cover crops were not commonly used as a conservation practice during the period covered by the farmer survey (2003–06). Only about 1 percent of the acres (13 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 Great Lakes Region, 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, utilizes gravitational energy to move water from higher elevations to lower elevations, such as moving water from a ditch at the head of a field, across the field to the lower end. Pumps are most often used to create the pressure in pressure systems, and the water is applied under pressure through pipes and nozzles of one form or another. 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.

About 4 percent of the cropped acres—559,000 acres—receive irrigation water in the Great Lakes Region. Most of the irrigated acres in the region are in the Eastern Michigan basin. Irrigation is exclusively by pressure systems. Most common pressure systems are center-pivot or linear-move systems with impact sprinkler heads (51 percent) followed by center-pivot or linear-move systems with more efficient low-pressure spray (34 percent). Traveling big gun sprinklers make up 8 percent. About 35 percent of the irrigated acres have systems with efficiencies at or near the current state of the art.

Nutrient Management Practices

Nitrogen and phosphorus are essential inputs to profitable crop production. Farmers apply these nutrients to the land as commercial fertilizers and manure to promote plant growth and increase crop yields. Not all of the nutrients applied to the land, however, are taken up by crops; some are lost to the environment, 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.

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

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

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

- All commercial fertilizer and manure applications are within 3 weeks prior to plant date, at planting, or within 60 days after planting.
- The method of application for commercial fertilizer or manure is some form of incorporation or banding or spot treatment or foliar applied.
- The rate of nitrogen application, including the sum of both commercial fertilizer and manure nitrogen available for crops in the year of application, is—
    - less than 1.4 times the amount of nitrogen removed in the crop yield at harvest for *each* crop, except for small grain crops; and
    - 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.

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

As shown in table 9, the majority of acres in the Great Lakes Region meet one or more of the criteria for nutrient management:

- 84 percent of cropped acres meet criteria for timing of nitrogen applications for one or more crops and 88 percent meet criteria for timing of phosphorus applications for one or more crops;
- 90 percent of cropped acres meet criteria for method of nitrogen application for one or more crops and 94 percent meet criteria for method of phosphorus application for one or more crops;
- 91 percent of cropped acres meet criteria for nitrogen application rate for one or more crops and;
- 5 percent of cropped acres have no nitrogen applied and 1.5 percent have no phosphorus applied.

Table 9. Nutrient management practices for the baseline conservation condition, Great Lakes Region

	Percent of acres without manure applied	Percent of acres with manure applied	Percent of all cropped acres
Nitrogen*			
No N applied to any crop in rotation	6	0	5
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	82	14	69
Some but not all crops have application of N (manure or fertilizer) within 3 weeks before planting or within 60 after planting	7	48	15
No crops in rotation have application of N (manure or fertilizer) within 3 weeks before planting or within 60 days after planting	5	38	12
Method of application			
All crops in rotation have N applied with incorporation or banding/foliar/spot treatment	50	47	50
Some but not all crops in rotation have N applied with incorporation or banding/foliar/spot treatment	37	53	40
No crops in rotation have N applied with incorporation or banding/foliar/spot treatment	7	1	6
Rate of application			
All crops in rotation meet the nitrogen rate criteria described in text	41	37	40
Some but not all crops in rotation meet the nitrogen rate criteria described in text	50	56	51
No crops in rotation meet the nitrogen rate criteria described in text	4	7	4
Timing and method and rate of application			
All crops meet the nitrogen rate criteria, timing criteria, and method criteria described above	20	5	18
Some but not all crops meet the nitrogen rate criteria, timing criteria, and method criteria described above	62	64	62
No crops meet the nitrogen rate , timing criteria, and method criteria described above	12	31	16
Phosphorus*			
No P applied to any crop in rotation	1.9	0.0	1.5
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	82	14	69
Some but not all crops have application of P (manure or fertilizer) within 3 weeks before planting or within 60 days after planting	12	49	19
No crops in rotation have application of P (manure or fertilizer) within 3 weeks before planting or within 60 days after planting	4	37	10
Method of application			
All crops in rotation have P applied with incorporation or banding/foliar/spot treatment	63	54	61
Some but not all crops in rotation have P applied with incorporation or banding/foliar/spot treatment	31	46	33
No crops in rotation have P applied with incorporation or banding/foliar/spot treatment	5	0	4
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	50	28	45
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	49	72	53
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	35	4	29
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	13	19	14
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	50	77	55
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	13	3	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	3	10
All sample points	100	100	100

Note: About 19 percent of cropped acres (2.8 million acres) have manure applied. Percents may not add to 100 because of rounding.

* These estimates include adjustments made to the reported data on nitrogen and phosphorus application rates from the survey because of missing data and data-entry errors. In the case of phosphorus, the 3-year data period for which information was reported was too short to pick up phosphorus applications made at 4- and 5-year intervals between applications, which is a common practice for producers adhering to sound phosphorus management techniques. Since crop growth, and thus canopy development which decreases erosion, is a function of nitrogen and phosphorus, it was necessary to add additional nitrogen and phosphorus when the reported levels were insufficient to support reasonable crop yields throughout the 47 years in the model simulation. The approach taken was to first identify crop samples that have application rates recorded erroneously or were under-reported in the survey. The model was used to identify these samples by running the simulation at optimal levels of nitrogen and phosphorus for crop growth. The set of crop samples identified were treated as if they had missing data. Additional nitrogen or phosphorus was added to these crop samples so that the total nitrogen or phosphorus use was similar to that for the unadjusted set of crop samples. About 29 percent of the acres received a nitrogen adjustment for one or more crops. About 36 percent of the acres received a phosphorus adjustment for one or more crops. Nitrogen and phosphorus were added by increasing the existing applications (thus preserving the reported timing and methods), when present, or were applied at plant. (For additional information on adjustment of nutrient application rates, see "Adjustment of CEAP Cropland Survey Nutrient Application Rates for APEX Modeling," available at http://www.nrcs.usda.gov/technical/nri/ceap.

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

- 69 percent of cropped acres meet criteria for timing of nitrogen and phosphorus applications on all crops.
- 50 percent of cropped acres meet criteria for method of nitrogen application on all crops and 61 percent meet criteria for method of phosphorus application on all crops.
- 40 percent of cropped acres meet criteria for nitrogen application rate on all crops and 45 percent meet criteria for phosphorus application rates for the full crop rotation.

Nutrients applied in the fall for a spring-planted crop are generally more susceptible to environmental losses than spring applications. Based on the survey, about 15 percent of the cropped acres in the Great Lakes Region received fall applications of either commercial nitrogen fertilizer or manure on at least one crop in the rotation. About 19 percent of cropped acres received fall applications of either commercial phosphorus fertilizer or manure on at least one crop in the rotation.

Acres with manure applied—about 19 percent of cropped acres in the region—generally meet the criteria for method of application at about the same frequency as acres with only commercial fertilizer applications. Criteria for timing and rate, however, are met less frequently for acres receiving manure:

- 14 percent of cropped acres receiving manure meet criteria for timing of nitrogen and phosphorus applications on all crops, compared to 82 percent for acres not receiving manure;
- 37 percent of cropped acres receiving manure meet criteria for nitrogen application rates on all crops, compared to 41 percent for acres not receiving manure; and
- 28 percent of cropped acres receiving manure meet criteria for phosphorus application rates, compared to 50 percent for acres not receiving manure.

The highest percentages of cropped acres with manure applied are in the Western Michigan basin and the Ontario basin—37 percent and 34 percent, respectively (appendix B, table B1).

Only a few acres meet all nutrient management criteria:

- 18 percent of the acres meet all criteria for nitrogen applications, while another 5 percent of cropped acres have no nitrogen applied;
- 29 percent of the acres meet all criteria for phosphorus applications, while another 1.5 percent of the acres have no phosphorus applied; and
- only 12 percent of cropped acres meet criteria for *both* phosphorus and nitrogen management (table 9), including acres not receiving nutrient applications.

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

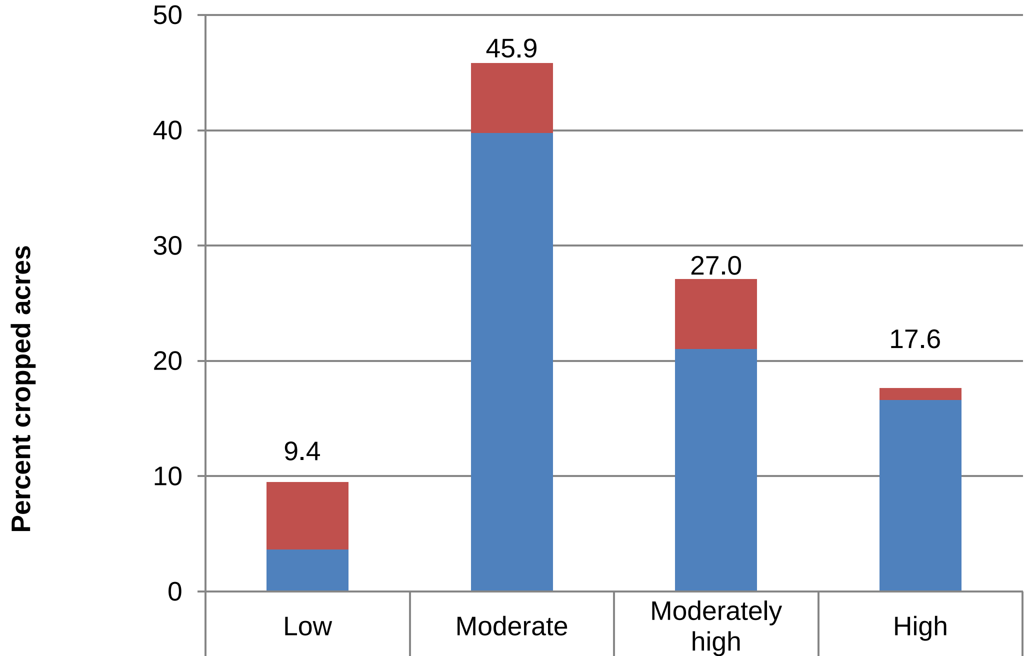
- 1.2 times the amount of nitrogen removed in the crop yield at harvest for *each* crop, except for small grain crops; and
- 1.5 times the amount of nitrogen removed in the crop yield at harvest for small grain crops.

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

Based on these treatment levels, about 18 percent of the acres in the Great Lakes Region have a high level of nitrogen management and about 30.5 percent have a high level of phosphorus management (figs. 9 and 10). Few acres with manure applied meet the criteria for the high treatment levels. About 9 percent of cropped acres have a low level of nitrogen management and 33 percent of the acres have a low level of phosphorus management.

Figure 9. Percent of cropped acres at four conservation treatment levels for nitrogen management, baseline conservation condition, Great Lakes Region



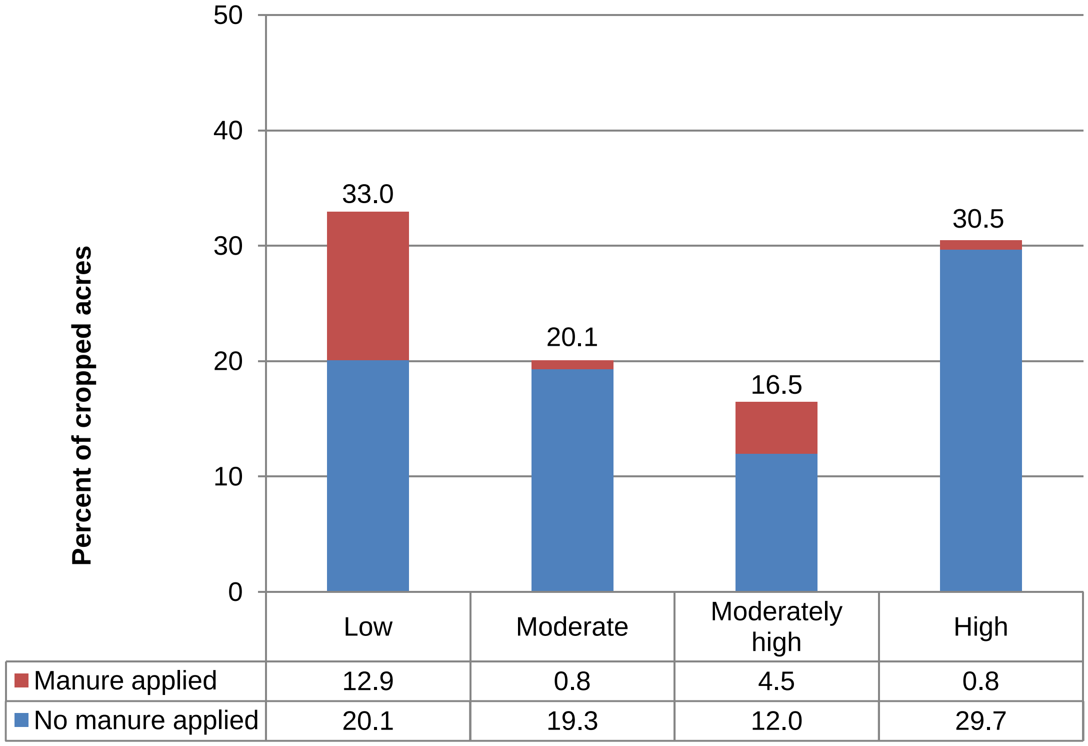
	Low	Moderate	Moderately high	High
Manure applied	5.8	6.1	6.0	1.0
No manure applied	3.6	39.8	21.0	16.6

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 grains, 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.

Note: See appendix B, table B3, for a breakdown of conservation treatment levels by Lake basin.

Figure 10. Percent of cropped acres at four conservation treatment levels for phosphorus management, baseline conservation condition, Great Lakes Region



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.

Note: See appendix B, table B3, for a breakdown of conservation treatment levels by Lake basin.

Pesticide Management Practices

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

Adoption of IPM systems 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 exist, where they exist, are important IPM tools. *Chemical pesticides* are applied as a last resort in suppression systems using a sound management approach, including selection of pesticides with low risk to non-target organisms.

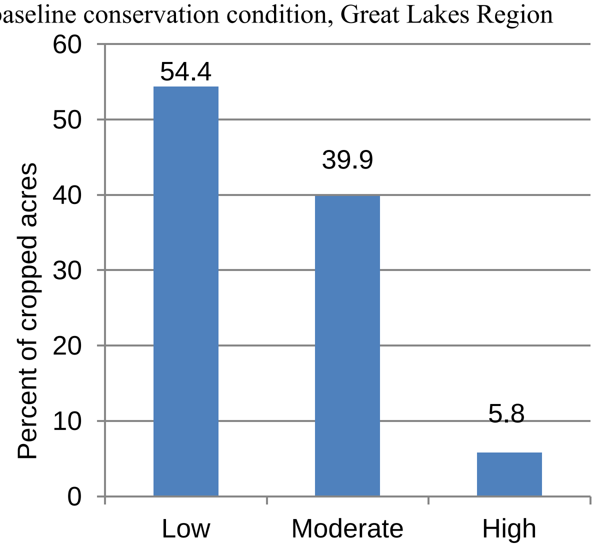
An IPM index was developed to determine the level of IPM activity for each sample point. The index was constructed as follows.

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

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

About 6 percent of the acres in the Great Lakes Region have a high level of IPM activity (fig. 11). About 40 percent have a moderate level of IPM activity, and 54 percent have a low level of IPM activity.

Figure 11. Integrated Pesticide Management indicator for the baseline conservation condition, Great Lakes Region



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

Table 10. Summary of survey responses to pest management questions, Great Lakes Region

Survey question	Number samples with "yes" response	Percent of cropped acres
Prevention		
Pesticides with different action rotated or tank mixed to prevent resistance	447	31
Plow down crop residues	290	22
Chop, spray, mow, plow, burn field edges, etc.	431	30
Clean field implements after use	440	29
Remove crop residue from field	116	9
Water management used to manage pests (irrigated samples only)	14	1
Avoidance		
Rotate crops to manage pests	1054	75
Use minimum till or no-till to manage pests	737	49
Choose crop variety that is resistant to pests	398	28
Planting locations selected to avoid pests	72	5
Plant/harvest dates adjusted to manage pests	75	5
Monitoring		
Scouting practice: general observations while performing routine tasks	453	31
Scouting practice: deliberate scouting	736	52
--Established scouting practice used	246	17
--Scouting due to pest development model	122	8
--Scouting due to pest advisory warning	219	15
Scouting done by: (only highest of the 4 scores is used)		
--Scouting by operator	523	36
--Scouting by employee	13	1
--Scouting by chemical dealer	122	8
--Scouting by crop consultant or commercial scout	96	7
Scouting records kept to track pests?	238	17
Scouting data compared to published thresholds?	425	29
Diagnostic lab identified pest?	57	4
Weather a factor in timing of pest management practice	364	26
Suppression		
Pesticides used?	1377	96
Weather data used to guide pesticide application	792	56
Biological pesticides or products applied to manage pests	61	4
Pesticides with different mode of action rotated or tank mixed to prevent resistance	447	31
Pesticide application decision factor (one choice only):		
--Routine treatments or preventative scheduling	774	52
--Comparison of scouting data to published thresholds	71	5
--Comparison of scouting data to operator's thresholds	111	8
--Field mapping or GPS	1	<1
--Dealer recommendations	231	17
--Crop consultant recommendations	64	4
--University extension recommendations	5	<1
--Neighbor recommendations	4	<1
--"Other"	53	4
Maintain ground covers, mulch, or other physical barriers	405	29
Adjust spacing, plant density, or row directions	191	14
Release beneficial organisms	11	1
Cultivate for weed control during the growing season	178	15
Number of respondents	1,418	100

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

Conservation Cover Establishment

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

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

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

As of 2003, about 31.5 million acres were enrolled in the CRP General Signup nationally, including about 593,000 in the Great Lakes Region (USDA/NRCS 2007). Approximately 40 percent of the cropland acres enrolled in the CRP in the Great Lakes Region is classified as highly erodible land. The inclusion of non-highly erodible land is due to both the expansion of enrollment eligibility criteria beyond soil erosion issues and the fact that farmers were allowed to enroll entire fields in the CRP if a specified portion of the field (varied by signup and eligibility criterion) met the criteria.

In the Great Lakes Region, 75.6 percent of the CRP land is planted to introduced grasses, 8.6 percent to wildlife habitat, 8.5 percent to trees, and 7.3 percent to native grasses. The plantings designated in the NRI database for each sample point were simulated in the APEX model. However, in all cases the simulated cover was a mix of species and all points included at least one grass and one clover species.

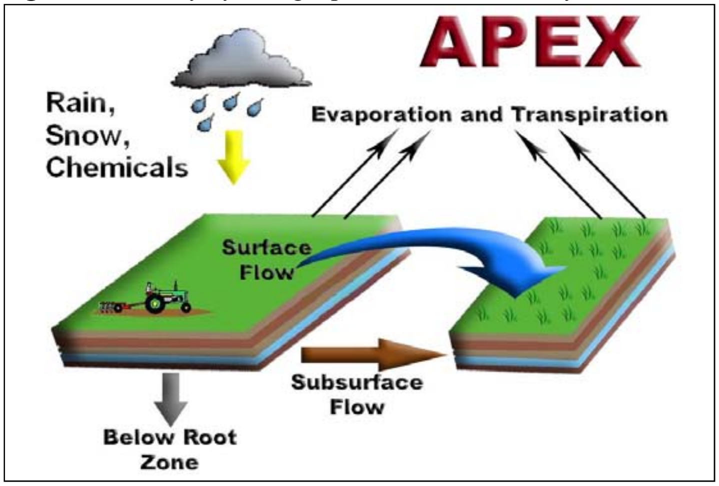
Chapter 4
Onsite (Field-Level) Effects of Conservation Practices

The Field-Level Cropland Model—APEX

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

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

Figure 12. Daily hydrologic processes simulated by APEX



On a daily basis, APEX simulates the farming operations used to grow crops, such as planting, tillage before and after planting, application of nutrients and pesticides, application of manure, irrigation, and harvest. Weather events and their interaction with crop cover and soil properties are simulated; these events affect crop growth and the fate and transport of water and chemicals through the soil profile and over land to the edge of the field. Over time, the chemical makeup and physical structure of the soil may change, which in turn affect crop yields and environmental outcomes. Crop residue remaining on the field after harvest is transformed into organic matter. Organic matter may build up in the soil over time, or it may degrade, 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.[11]

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

Simulating the No-Practice Scenario

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

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

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

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

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

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 Great Lakes Region were estimated by contrasting model output from the no-practice scenario to model output from the baseline conservation condition (2003–06). The only difference between the no-practice scenario and the baseline conservation condition is that the conservation practices are removed or their effects are reversed in the no-practice scenario simulations. There were usually several alternatives that could be used to represent "no practices." The no-practice representations derived for use in this study conformed to the following guidelines.

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

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

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

- **Moderation:** The no-practice scenario should provide a reasonable level of 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 Great Lakes Region

Practice adjusted	Criteria used to determine if a practice was in use	Adjustment made to create the no-practice scenario
Structural practices	1. Overland flow practices present	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 1.83 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 1.71 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: 1) water losses from the water source to the field and evaporation losses with sprinkler systems, 2) percolation losses below the root-zone during irrigation, and 3) 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.

In the no-practice representation, all conservation practices, such as Irrigation Water Management and Irrigation Land Leveling, were removed and samples with pressurized systems, such as center pivot, side roll, and low flow (drip), were changed to "hand move sprinklers," which represents an early form of pressure system with connecting pipes. The "Big Gun" systems, which make up 8 percent of the irrigated acres, are by and large already less efficient than the "hand move sprinklers," and most were not converted. However, 2.6 percent of the irrigated acres that were served by "Big Gun" systems are more efficient than the "hand move sprinklers," and these were converted in the no-practice representation.

For the no-practice scenario, the percentage of irrigated acreage with hand-move lines with impact sprinkler heads was increased to 94.6 percent (from 0.5 percent in the baseline conservation condition) and 5.4 percent retained the Big Gun systems that were in use.

No-practice representation of nutrient management practices

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

The NRCS Nutrient Management standard (590) allows a variety of methods to reduce nutrient losses while supplying a sufficient amount of nutrient to meet realistic yield goals. The standard addresses nutrient loss in 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 1.70 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 1.70 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 rotation and removed at harvest. The threshold s 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 1.8 times the harvest removal rate for the crop rotation. The ratio of 1.8 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 1.8 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 1.7 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.[13] Farmers, of course, have such options, and environmentally conscientious farmers make tradeoffs to reduce environmental risk. But without better information on the nature of the pest problem both at the field level and in the surrounding area, modelers have to resort to prescriptive and generalized approaches to simulate alternative pesticides and application techniques, which would inevitably be inappropriate for many, if not most, of the acres simulated.

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

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

One of the choices for methods of pesticide application on the survey was "spot treatment." Typically, spot treatments apply to a small area within a field and are often treated using a hand-held sprayer. Spot treatment is an IPM practice, as it requires scouting to determine what part of the field to treat and avoids treatment of parts of the field that do not have the pest problem. The reported rate of application for spot treatments was the rate per acre treated. For the baseline simulation, it was assumed that all spot treatments covered 5 percent of the field. Since the APEX model run and associated acreage weight for the sample point represented the whole field, the application rate was adjusted downward to 5 percent of the per-acre rate reported for the baseline scenario. For the no-practice scenario, the rate as originally reported was used, simulating treatment of the entire field rather than 5 percent of the field. In the Great Lakes Region, there were 10 sample points with spot treatments, representing about 1percent of the cropped acres.

Partial field treatments were simulated in a manner similar to spot treatments. For the baseline scenario, application rates were reduced proportionately according to how much of the field was treated. For the no-practice scenario, the rate as reported in the survey was used, simulating treatment of the entire field. However, this adjustment for the no-practice scenario was only done for partial field treatments on less than one-third of the field, as larger partial field treatments could have been for reasons unrelated to IPM. In the Great Lakes Region, there were 14 sample points with partial field treatments, representing about 1 percent of the cropped acres.

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 1 time for each crop, one week after its original application.

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

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

Effects of Practices on Fate and Transport of Water

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

Baseline condition for cropped acres

Precipitation and irrigation are the sources of water for a field. Annual precipitation over the 47-year simulation averaged about 33.6 inches in this region (table 12). (Also see figs. 5 and 6.) Only about 4 percent of cropped acres are irrigated, at an average application rate of 8 inches per year.

Most of the water that leaves the field is lost through evaporation from the soil and plant surfaces and transpiration by plants (evapotranspiration) (fig. 13). Evapotranspiration is the dominant loss pathway for 99 percent of cropped acres. (The dominant loss pathway was determined for each sample point as the pathway with the highest loss.) On average, about 64 percent of the water loss for cropped acres in this region is through evapotranspiration (table 12). Model results indicate that evapotranspiration losses vary, however, according to soil characteristics and land cover; evapotranspiration ranges from about 40 percent to 80 percent of the total amount of water that leaves the field (fig. 14).

Subsurface flow pathways are the second largest source of water loss at an average of about 8 inches per year for cropped acres, on average (table 12). 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.

The percentage of water loss represented by subsurface flows averages about 23 percent for cropped acres (table 12). However, this percentage varies from less than 10 percent to 40 percent for cropped acres in the Great Lakes Region, as shown in figure 14.

Surface water runoff averages about 13 percent of water loss for cropped acres (table 12), ranging from about 5 percent to 30 percent (fig. 14). Average surface water loss for cropped acres is about 4.5 inches per year (table 12). The amount of surface water runoff varies from acre to acre, ranging from an annual average of about 2 inches per year for some acres to over 8 inches per year (fig. 15).

Figure 13. Estimates of average annual water lost through three loss pathways for cropped acres in the Great Lakes Region, baseline conservation condition

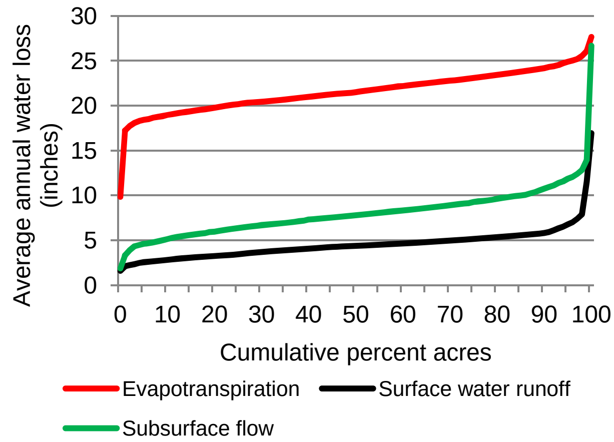
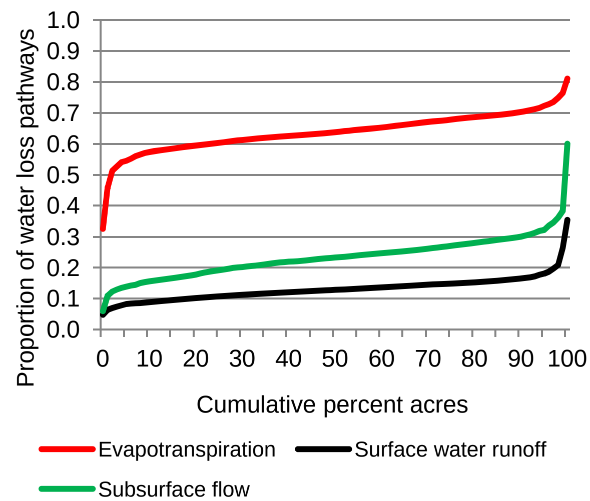


Figure 14. Cumulative distributions of the proportion of water lost through three loss pathways for cropped acres, Great Lakes Region, baseline conservation condition



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.

Figure 15. Estimates of average annual surface water runoff for cropped acres in the Great Lakes Region

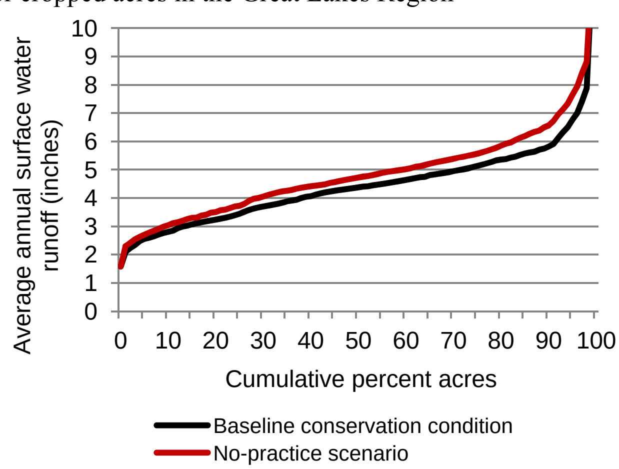


Table 12. Field-level effects of conservation practices on water loss pathways for cultivated cropland in the Great Lakes Region

Model simulated outcome	Baseline conservation condition	No-practice scenario	Reduction due to practices	Percent reduction
Cropped acres (14.8 million acres)				
Water sources				
Non-irrigated acres				
Average annual precipitation (inches)	33.6	33.6	0.0	0
Irrigated acres				
Average annual precipitation (inches)	35.3	35.3	0.0	0
Average annual irrigation water applied (inches)*	8.2	15.2	7.0	46
Water loss pathways				
Average annual evapotranspiration (inches)	21.6	21.7	0.1	1
Average annual surface water runoff (inches)	4.5	4.9	0.4	8
Average annual subsurface water flows (inches)**	7.9	7.5	-0.5***	-6***
Land in long-term conserving cover (0.6 million acres)				
Water sources*				
Average annual precipitation (inches)	33.8	33.8	0	0
Average annual irrigation water applied (inches)*	0.0	0.8	0.8	100
Water loss pathways				
Average annual evapotranspiration (inches)	20.4	21.8	1.4	6
Average annual surface water runoff (inches)	3.2	5.0	1.8	36
Average annual subsurface water flow (inches)**	10.4	7.7	-2.7***	-35***

* About 4 percent of the cropped acres in the Great Lakes Region are irrigated. Land in long-term conserving cover was not irrigated, but some farming practices used to simulate a cropped condition to represent the no-practice scenario included irrigation. Values shown in the table for land in long-term conserving cover are averages over all acres, including non-irrigated acres.
** Subsurface flow pathways include: (1) deep percolation to groundwater, including groundwater return flow; (2) subsurface flow intercepted by tile drains or drainage ditches; (3) lateral subsurface outflow; and (4) quick-return subsurface flow.
*** Represents an average gain in subsurface flows of 0.5 inch per year (6 percent increase) for cropped acres due to the use of conservation practices; represents an average gain of 2.7 inches in subsurface flow for land in long-term conserving cover.
Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text.
Note: Model simulation results for the baseline conservation condition are presented in appendix B for the Lake basins.

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—

- the depth and spacing of the tile drainage field,
- the extent of the tile drainage network,
- the proportion of the field, or other fields, that benefited from the tile drainage system, and
- the extent to which overland flow and subsurface flow from surrounding areas enters through tile surface inlets.

Without this additional information, it is not possible to accurately separate out the various components of subsurface flow when tile drainage systems are present.

In the Great Lakes Region, about half of the cropped acres have some portion of the field that is tile drained, according to the farmer survey (38 percent for the Eastern Lake Michigan basin, 22 percent for the Western Lake Michigan basin, 74 percent for the Lake Erie and Lake Huron basins, and 56 percent for the Lake Ontario basin). For these acres, about three-fourths of the subsurface flow in the 2003–06 baseline—as well as the soluble nutrients carried in the subsurface flow—was allocated by the physical process model (APEX) to tile drainage flow in this region, ranging from 58 percent for the Western Lake Michigan basin to 78 percent for the Lake Erie basin.

Surface water runoff is highest in the Lake Ontario basin, averaging 6.6 inches per year, and lowest in the Lake Huron and Western Lake Michigan basins, averaging 3.4 and 3.6 inches per year, respectively (appendix B, table B1). Subsurface flow is highest in the Eastern Lake Michigan basin and the Lake Ontario basin, averaging 9.9 and 8.7 inches per year, respectively.

Effects of conservation practices on cropped acres

Structural water erosion control practices, residue management practices, and reduced tillage slow the flow of surface water runoff and allow more of the water to infiltrate into the soil.[14] Model simulations indicate that conservation practices have reduced surface water runoff by about 0.4 inch per year averaged over all acres, representing an 8-percent reduction for the region (table 12).

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

Reductions in surface water runoff due to conservation practices range from less than zero to above 1 inch per year for most cropped acres in the region (fig. 16). The variability in reductions due to practices reflects different levels of conservation treatment as well as differences in precipitation and inherent differences among acres for water to run off.

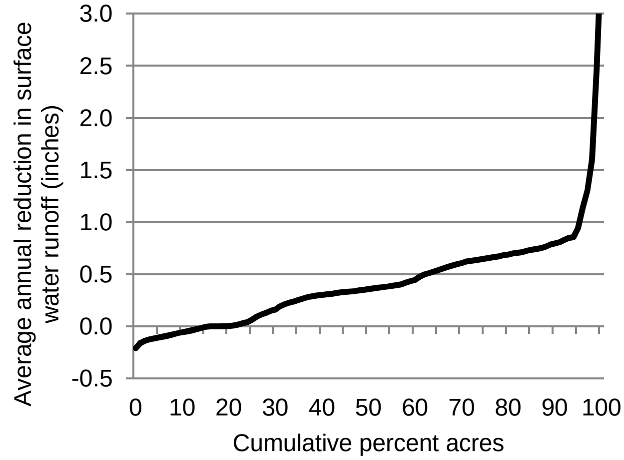
Use of improved irrigation systems in the Great Lakes Region increases irrigation efficiency from 41 percent in the no-practice scenario to 62 percent in the baseline scenario. This change in efficiency represents an annual decreased need of water use of about 7 inches where irrigation is used (table 12).

Land in long-term conserving cover

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

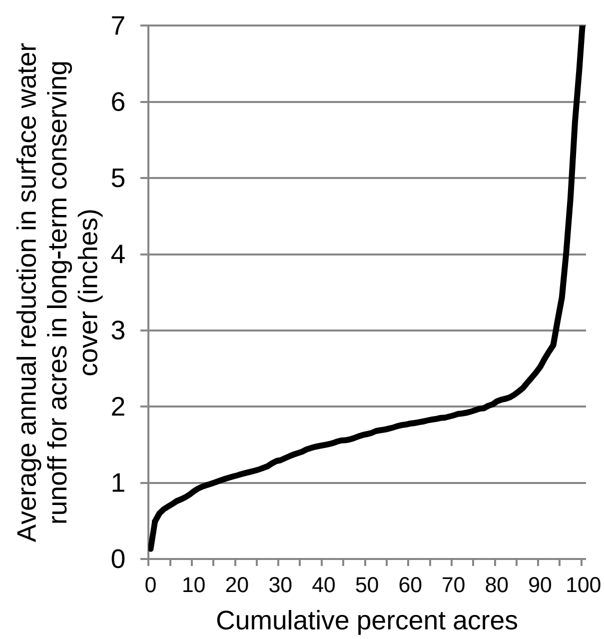
Reductions in surface water runoff due to conversion to long-term conserving cover average 1.8 inches per year in this region (table 12), but range from zero to more than 5 inches per year for some acres (fig. 17).

Figure 16. Estimates of average annual reduction in surface water runoff due to the use of conservation practices on cropped acres in the Great Lakes Region



Note: About 14 percent of cropped acres had less surface water runoff in the no-practice scenario than the baseline, resulting in negative reductions. These gains in surface water runoff when conservation practices are applied can occur on soils with low to moderate potential for runoff when: (1) excessive nutrient application rates in the no-practice scenario produces more biomass, lowering soil moisture and thus reducing runoff, or (2) tillage of the surface soil in the no-practice scenario reduces surface compaction and crusting, producing temporary surface roughness that in turn reduces runoff.

Figure 17. Estimates of average annual reduction in surface water runoff due to conversion to long-term conserving cover in the Great Lakes Region



[14] 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.

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 1,418 sample points used to represent cropped acres in the Great Lakes Region and for each of the 425 sample points used to represent land in long-term conserving cover. Cumulative distributions show the full set of estimates and thus demonstrate how conditions and the effects of conservation practices vary throughout the region.

Cumulative distributions shown in this report are plots of the value for each percentile. In figure 15, for example, the curve for average annual surface water runoff for the baseline conservation condition consists of each of the percentiles of the distribution of 1,418 surface water runoff estimates, weighted by the acres associated with each sample point. The 10^{th} percentile for the baseline conservation condition is 2.8 inches per year, indicating that 10 percent of the acres have 2.8 inches or less of surface water runoff, on average. Similarly, the same curve shows that 25 percent of the acres have surface water runoff less than 3.4 inches per year. The 50^{th} percentile—the median—is 4.4 inches per year, which in this case is close to the mean value of 4.5 inches per year. At the high end of the distribution, 90 percent of the acres in this region have surface water runoff less than 5.8 inches per year; and conversely, 10 percent of the acres have surface water runoff greater than 5.8 inches per year.

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

Figure 16 shows the effects of conservation practices on surface water runoff using the distribution of the *reduction* in surface water runoff, calculated as the outcome for the no-practice scenario minus the outcome for the baseline conservation condition at each of the 1,418 cropped sample points. This distribution shows that, while the mean reduction is 0.4 inch per year, 5 percent of the acres have reductions due to conservation practices greater than one inch per year and 14 percent of the acres actually have small increases in surface water runoff (i.e., negative reductions) as a result of soil erosion control conservation practice use. (See footnote to figure 16 for an explanation of the conditions that result in gains in surface water runoff due to conservation practices.)

Effects of Practices on Wind Erosion

Wind 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.

Wind erosion is a significant resource concern for some cropped acres in the Great Lakes Region. 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

For all cropped acres, model simulations show that the average annual rate of wind erosion is 0.85 ton per acre (table 13). Up to 15 percent of cropped acres have wind erosion rates greater than 4 tons per acre in one or more years (fig. 18). In the most extreme year included in the model simulations (representing 1967), annual wind erosion exceeded 8 tons per acre for 8 percent of the cropped acres.

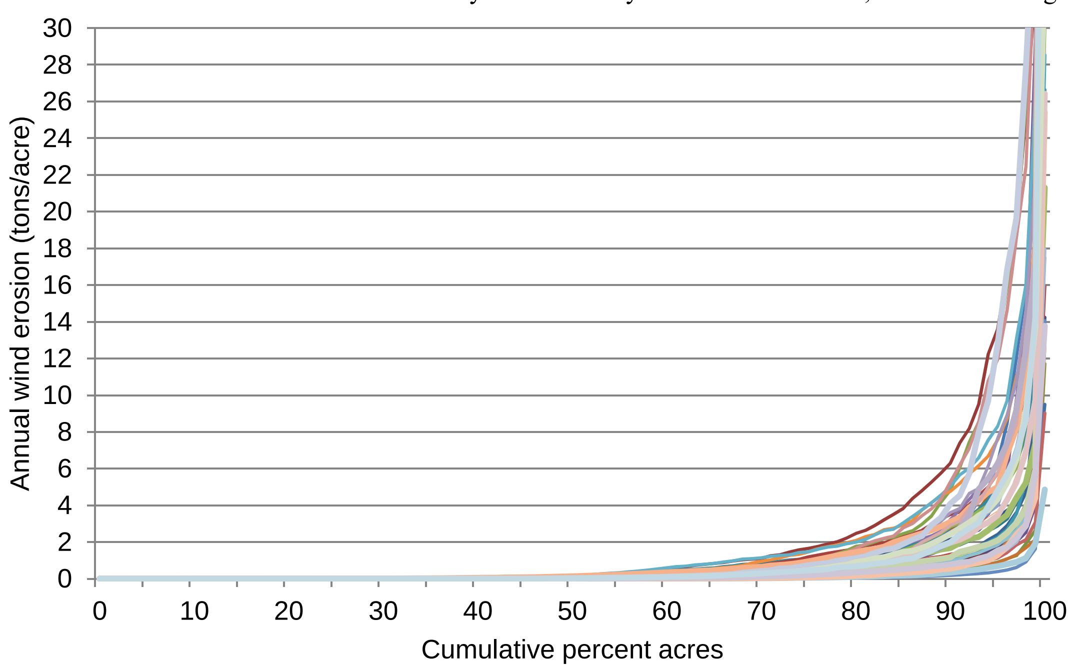
Average annual wind erosion exceeds 2 tons per acre on 13 percent of cropped acres and exceeds 4 tons per acre on 5 percent of cropped acres in the Great Lakes Region (fig. 19). The highest levels of wind erosion occur in the Eastern Lake Michigan and Lake Huron basins, where annual wind erosion rates average 1.5 tons per acre per year and 2.4 tons per acre per year, respectively (appendix B, table B1). Annual wind erosion rates for other basins average less than 0.5 ton per acre per year.

Table 13. Average annual wind erosion (tons/acre) for cultivated cropland in the Great Lakes Region

	Baseline conservation condition	No-practice scenario	Reduction due to practices	Percent reduction
Cropped acres	0.85	1.51	0.659	44
Land in long-term conserving cover	<0.0001	0.0366	0.0326	100

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

Figure 18. Distribution of annual wind erosion rate for each year of the 47-year model simulation, Great Lakes Region



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

Effects of 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 4 percent of the cropped acres in the Great Lakes Region. However, other practices common in the region, such as residue and tillage management, reduced tillage, and various water erosion control practices, are also effective in reducing wind erosion. Model simulations indicate that conservation practices have reduced the average wind erosion rate by 44 percent in the region (table 13).

Without conservation practices, the average annual wind erosion would have been 1.5 tons per acre per year compared to 0.85 ton per acre average for the baseline conservation condition. On average, conservation practices have reduced wind erosion by 0.7 tons per acre. Reductions in wind erosion due to conservation practices are much higher for some acres than others, reflecting both the level of treatment and the inherent erodibility of the soil. For about 25 percent of cropped acres, the average annual wind erosion reduction due to practices is greater than 1 ton per acre (fig. 20).

Figure 19. Estimates of average annual wind erosion for cropped acres in the Great Lakes Region

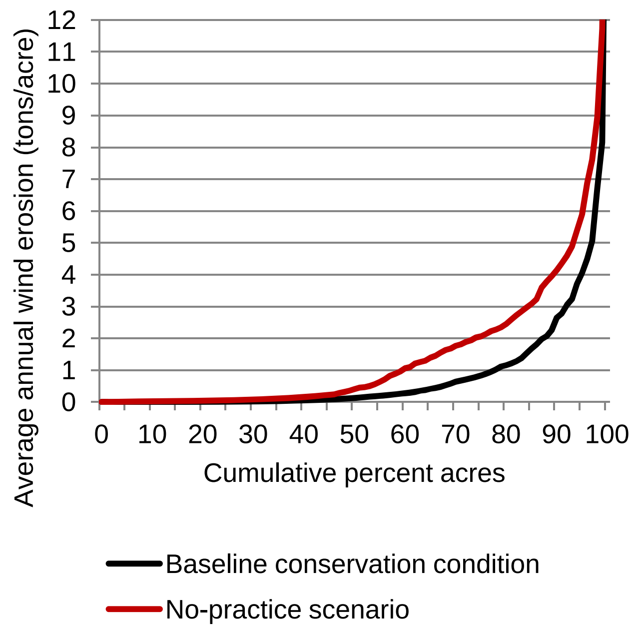
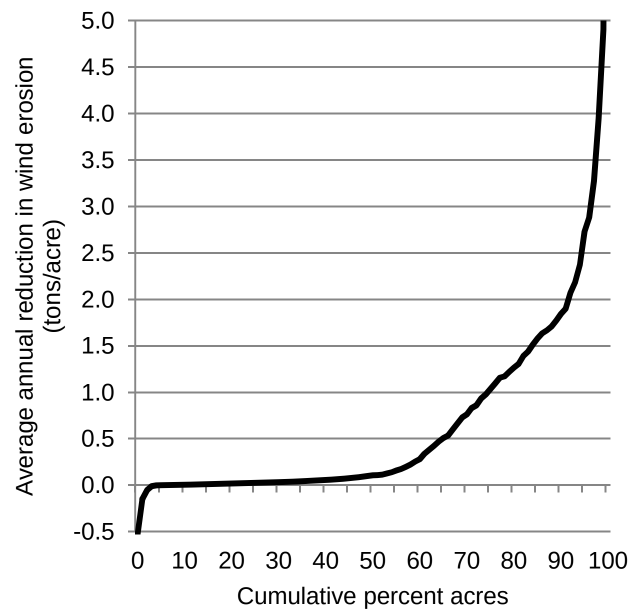


Figure 20 Estimates of average annual reduction in wind erosion due to the use of conservation practices on cropped acres in the Great Lakes Region



Effects of Practices on Water Erosion and Sediment Loss

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

The term "sediment loss," as used in this report, refers to the sediment that is transported beyond the edge of the field by water. Soil erosion and sedimentation are separate but interrelated resource concerns. Soil erosion is the detachment and transport of soil particles, while sedimentation is that portion of the eroded material that settles out in areas onsite or offsite. Sediment loss, as estimated in this study, includes the portion of the sheet and rill eroded material that settles offsite as well as some sediment that originates from gully erosion processes.[15] Edge-of-field conservation practices are designed to filter out a portion of the material and reduce sediment loss. Sediment is composed of detached and transported soil minerals, organic matter, plant and animal residues, and associated chemical and biological compounds.

The Great Lakes region has one of the lowest proportions of cropland classified as highly erodible for water erosion (17 percent) when compared to other agricultural areas. Most of these soils occur in the western Great Lakes and in the Finger Lake region of New York. They developed in till plain deposits and moraines on undulating to rolling or steep slopes. They are often relatively shallow agricultural soils with approximately half of the HEL lands classified with a soil loss tolerance (T) of 3 tons per acre per year.

Sheet and rill erosion

Model simulations show that sheet and rill erosion on cropped acres in the Great Lakes Region averages about 0.44 ton per acre per year (table 14). Sheet and rill erosion rates are higher for highly erodible land, averaging 1.0 ton per acre per year compared to the average annual rate for non-highly erodible land of 0.32 ton per acre.

Model simulation results also show that conservation practices have reduced sheet and rill erosion on cropped acres in the Great Lakes Region by an average of 0.23 ton per acre per year, representing a 34-percent reduction on average (table 14). While the average annual reduction in sheet and rill erosion for highly erodible land is more than three times that for non-highly erodible acres (table 14), the percent reduction due to conservation practices is about the same. For land in long-term conserving cover, sheet and rill erosion has been reduced from 0.9 ton per acre per year if cropped without conservation practices to 0.02 ton per acre (table 14), on average.

Sediment loss from water erosion

Baseline condition for cropped acres. The average annual sediment loss for cropped acres in the Great Lakes Region is 0.63 ton per acre per year, according to the model simulation (table 14). As seen for sheet and rill erosion, sediment loss for highly erodible land is much higher than for non-highly erodible land, even though a higher proportion of highly erodible acres have structural water erosion control practices in use. Sediment loss is highest in the Lake Ontario basin, averaging 1.9 tons per acre per year (appendix B, table B1). Average sediment loss ranges from 0.24 ton per acre per year to 0.91 ton per acre per year among the other basins in the region.

On an annual basis, sediment loss can vary from year to year, although high losses are restricted to a few acres. Figure 21 shows that, with the conservation practices currently in use in the Great Lakes Region, annual sediment loss is below 2 tons per acre for about 85 percent of the acres under all conditions, including years with high precipitation. In contrast, sediment loss exceeds 6 tons per acre in one or more years on about 5 percent of the cropped acres.

Figure 21 also illustrates the extent to which high sediment losses are restricted to a minority of acres within the region, even during years with high precipitation. These are the acres that have the highest inherent vulnerability to water erosion and have inadequate soil erosion control.

Effects of conservation practices on cropped acres. Model simulations indicate that the use of conservation practices in the Great Lakes Region has reduced average annual sediment loss from water erosion by 47 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 1.2 tons per acre per year compared to 0.63 ton per acre average for the baseline conservation condition. Figure 22 shows that about 15 percent of the acres would have more than 2 tons per acre per year sediment loss without practices, on average, compared to 7 percent with conservation practices.

Reductions in sediment loss due to conservation practices are much higher for some acres than others, reflecting both the level of treatment and the inherent erodibility of the soil. For about 60 percent of cropped acres, the average annual sediment loss reduction due to practices is less than 0.25 ton per acre (fig. 23). The top 10 percent of the acres had reductions in average annual sediment loss greater than 1.4 tons per acre.

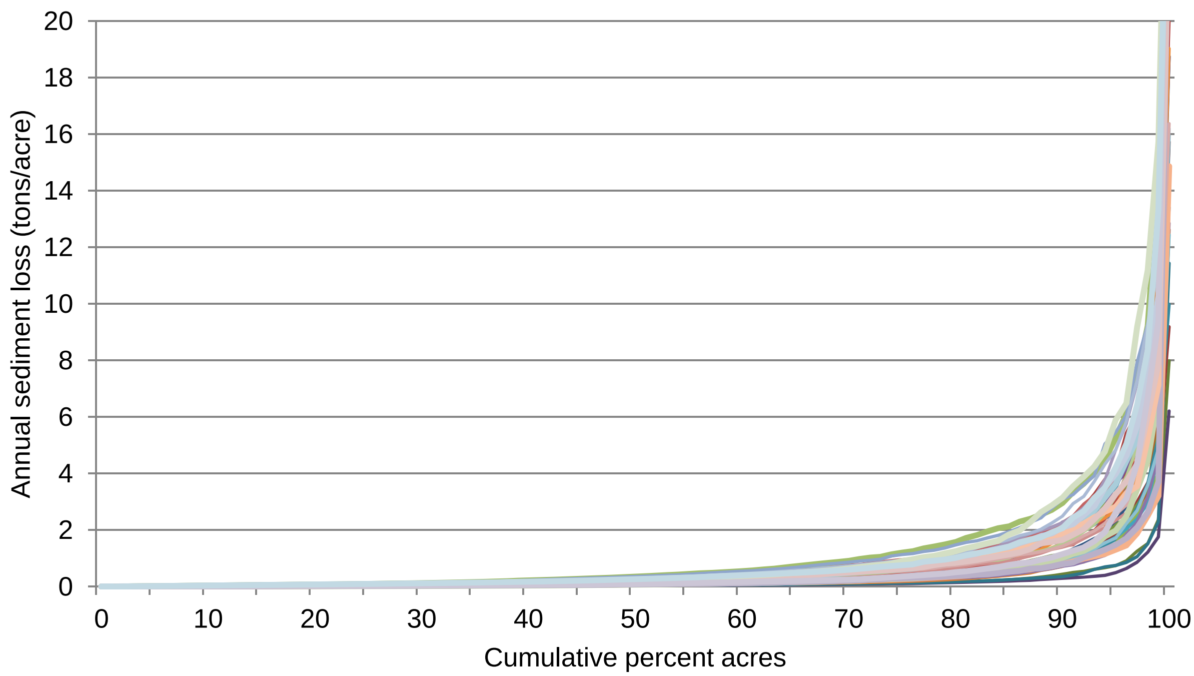
[15] For this study, the APEX model was set up to estimate sediment loss using a modified version of USLE, called MUSS, which uses an internal sediment delivery ratio to estimate the amount of eroded soil that actually leaves the boundaries of the field. A large percentage of the eroded material is redistributed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

Table 14. Field-level effects of conservation practices on erosion and sediment loss for cultivated cropland in the Great Lakes Region

Model simulated outcome	Baseline conservation condition	No-practice scenario	Reduction due to practices	Percent reduction
Cropped acres (14.8 million acres)				
Average annual sheet and rill erosion (tons/acre)*	0.44	0.66	0.23	34
Average annual sediment loss at edge of field due to water erosion (tons/acre)**	0.63	1.20	0.56	47
Highly erodible land (17 percent of cropped acres)				
Average annual sheet and rill erosion (tons/acre)*	1.01	1.54	0.53	34
Average annual sediment loss at edge of field due to water erosion (tons/acre)	1.60	3.25	1.65	51
Non-highly erodible land (83 percent of cropped acres)				
Average annual sheet and rill erosion (tons/acre)*	0.32	0.49	0.16	34
Average annual sediment loss at edge of field due to water erosion (tons/acre)	0.44	0.78	0.34	44
Land in long-term conserving cover (0.6 million acres)				
Average annual sheet and rill erosion (tons/acre)*	0.02	0.86	0.84	98
Average annual sediment loss at edge of field due to water erosion (tons/acre)	0.02	1.62	1.60	99

* Estimated using the Revised Universal Soil Loss Equation.
**Estimated using MUSS, 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.
Note: Model simulation results for the baseline conservation condition are presented in appendix B for the Lake basins.

Figure 21. Distribution of annual sediment loss for each year of the 47-year model simulation, Great Lakes Region



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

Cropped acres with a combination of structural practices and residue and tillage management typically have the highest percent reduction in sediment loss (table 15). Acres that are treated with structural practices, meet tillage intensity criteria for no-till or mulch till, and are gaining soil organic carbon (about 13 percent of cropped acres) have reduced sediment loss by 80 percent, on average. For these treated acres, annual sediment loss averages only about 0.2 ton per acre.

Land in long-term conserving cover. Acres in long-term conserving cover have very little erosion or sediment loss, and thus show nearly 100 percent reductions when compared to a cropped condition (table 14). If these 593,000 acres were still being cropped without any conservation practices, sediment loss would average about 1.62 tons per acre per year for these acres.

Reductions in sediment loss for land in long-term conserving cover compared to the same acres with crops and no conservation practices vary, as shown in figure 24. About half of the acres in long-term conserving cover have reductions of less than 1 ton per acre per year in this region. Reductions greater than 5 tons per acre per year occur on about 5 percent of the acres with long-term conserving cover.

Figure 22. Estimates of average annual sediment loss for cropped acres in the Great Lakes Region

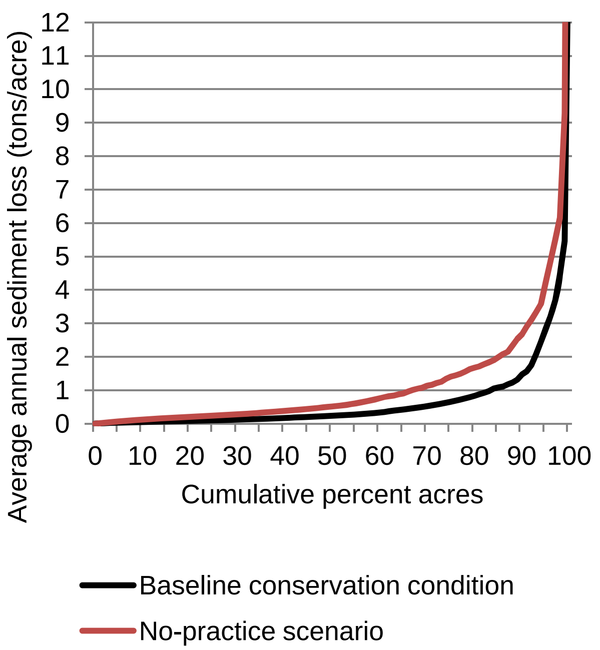
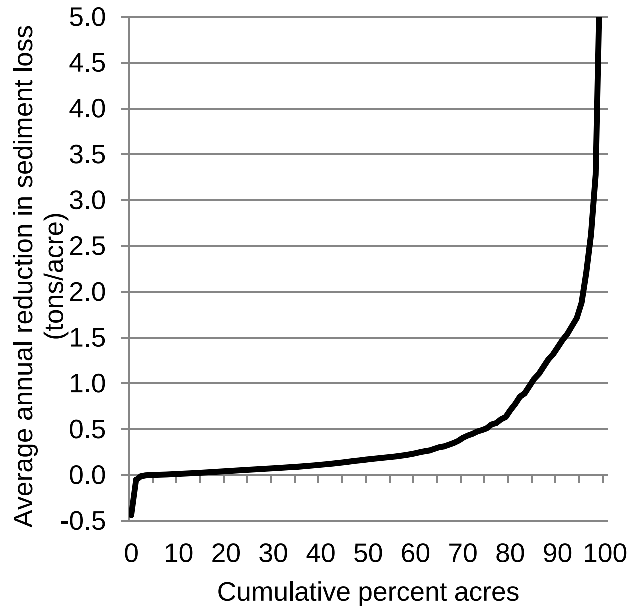


Figure 23 Estimates of average annual reduction in sediment loss due to the use of conservation practices on cropped acres in the Great Lakes Region



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

Figure 24. Estimates of average annual reduction in sediment loss due to conversion to long-term conserving cover in the Great Lakes Region

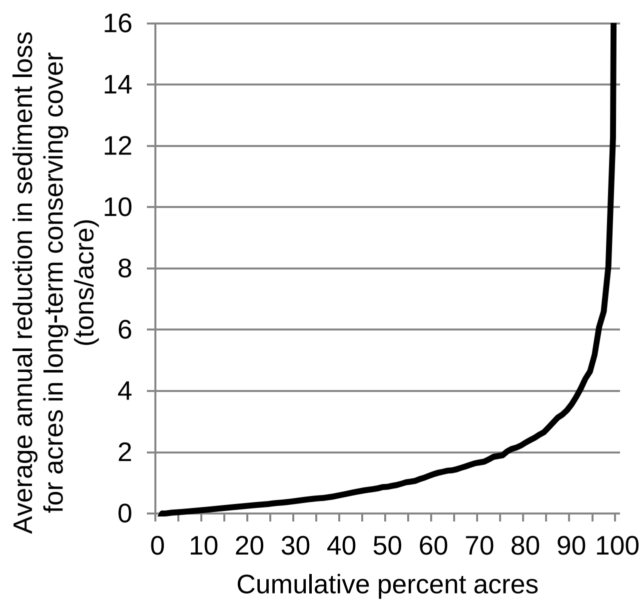


Table 15. Estimates of effects of combinations of structural practices and residue and tillage management on average annual sediment loss for cropped acres in the Great Lakes Region

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	30	0.31	0.54	0.22	42
No-till or mulch till with carbon loss, no structural practices	30	0.90	1.25	0.35	28
Some crops with reduced tillage, no structural practices	7	0.77	1.31	0.53	41
Structural practices and no-till or mulch till with carbon gain	13	0.21	1.07	0.85	80
Structural practices and no-till or mulch till with carbon loss	9	0.73	2.23	1.50	67
Structural practices and some crops with reduced tillage	1	1.09	2.09	1.00	48
Structural practices only	3	0.69	3.69	3.00	81
No water erosion control treatment	6	1.37	1.37	0.00	0
All acres	100	0.63	1.20	0.56	47

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 Great Lakes Region is somewhat less conducive to maintaining and enhancing soil organic carbon in cultivated cropland soils relative to landscapes and climate of the soils in the Midwest. The region is colder than the Upper Mississippi River Basin with only 120 to 170 frost free days in much of the region as compared to 170 to 210 frost free days in the Upper Mississippi. In natural settings the colder climate and higher rainfall would tend to be more conducive to increasing soil organic carbon, but with cropland the biological mixing of surface residues is much less and these residues tend to remain on the surface where they are degraded and oxidized before appreciable amounts can be sequestered. The soils in this region developed primarily from glacial materials and in glacial lake beds and tend to be inherently fertile, but the shorter growing season for agronomic crops contribute to their lower carbon stores relative to regions of the country such as the Upper Mississippi River Basin.

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

Baseline condition for cropped acres

Model simulation shows that for the baseline conservation condition the average annual soil organic carbon change is a loss of about 58 pounds per acre per year, on average (table 16), with about 46 percent of the acres gaining annually in soil organic carbon and 54 percent of cropped acres losing soil organic carbon, on average. These estimates account for losses of carbon with sediment removed from the field by wind and water erosion. Loss of soil organic carbon due to wind and water erosion averages about 179 pounds per acre per year for the baseline conservation condition (table 16).

Average annual change in soil organic carbon varies among the basins in the Great Lakes Region, averaging a gain of 66 pounds per acre per year in the Western Lake Erie subregion (code 410) of the Lake Erie basin to an average loss of 195 pounds per acre in the Lake Ontario basin (appendix B, table B1).

Cropped acres that are gaining soil organic carbon every year provide soil quality benefits that enhance production and reduce the potential for sediment, nutrient, and pesticide losses. Soil organic carbon improves the soil's ability to function with respect to nutrient cycling, improves water holding capacity, and reduces erodibility. However, enhancement of carbon stores on a scale seen in the Midwestern basins could only occur in this region with shifts in crop mixes toward higher residue rotations. The Great Lakes region has a higher concentration of dairy operations and therefore, a higher incidence of corn silage which leaves less residue for increasing soil carbon stores.

Given the challenging nature of the inherent conditions of this region, maintenance of soil organic carbon is also an important benchmark. Cropping systems can be considered to be maintaining soil organic carbon if average annual losses do not exceed 100 pounds per acre per year; this rate of change is typically too small to detect via typical soil sampling over a 20-year period. Applying this criterion, about 25 percent of the acres in the region would be considered to be maintaining (but not enhancing) soil organic carbon. When combined with acres enhancing soil organic carbon, a total of 71 percent of the acres in the region would be either maintaining or enhancing soil organic carbon (fig. 25).

Effects of conservation practices on cropped acres

Without conservation practices, the annual change in soil organic carbon would be an average loss of 97 pounds per acre per year, compared to an average loss of only 58 pounds per acre for the baseline (table 16). Thus, conservation practices in the region have resulted in an average annual gain in soil organic carbon of 39 pounds per acre per year on cropped acres.

However, average annual change in soil organic carbon varies considerably among acres in the region, as shown in figure 25. For the baseline conservation condition, the 46 percent of acres gaining soil organic carbon have an average annual gain of 101 pounds per acre per year. If conservation practices were not in use, only 37 percent of the acres would be gaining soil organic carbon and the annual rate of gain would be about the same—99 pounds per acre per year on those acres.

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

Some of the increased gain in soil organic carbon due to conservation practices is the result of soil erosion control—keeping soil organic carbon on the field promotes soil quality. If conservation practices were not in use, loss of soil organic carbon due to wind and water erosion would average 198 pounds per acre per year, compared to 179 pounds per acre with conservation practices (table 16).

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 39 pounds per acre due to conservation practice use is equivalent to a carbon dioxide emission reduction of 1.1 million U.S. tons of carbon dioxide for the Great Lakes Region.

Figure 25. Estimates of average annual change in soil organic carbon for cropped acres in the Great Lakes Region

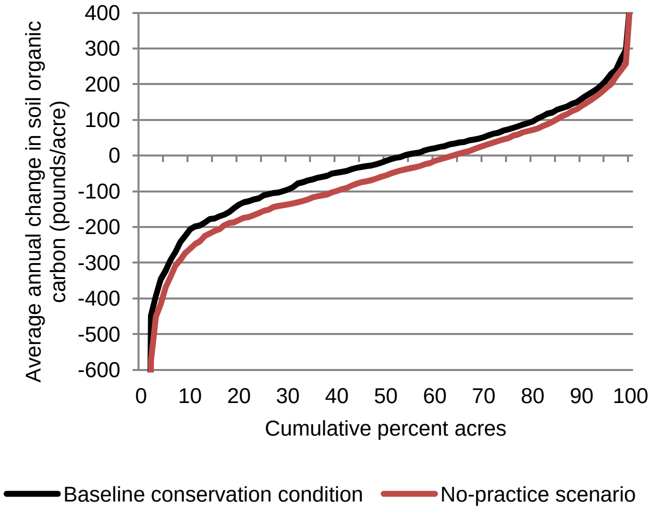
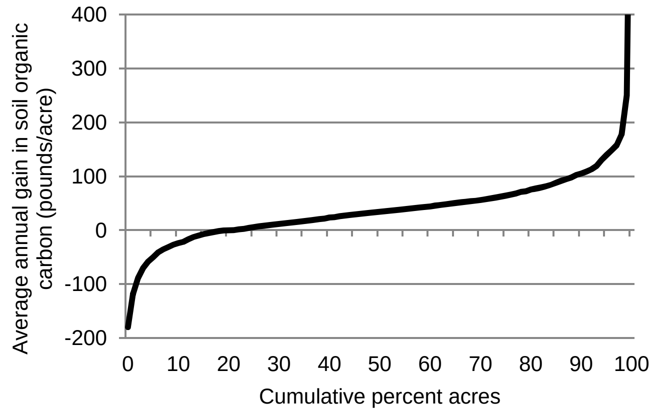


Figure 26. Estimates of average annual gain in soil organic carbon due to the use of conservation practices on cropped acres in the Great Lakes Region



Note: About 20 percent of the acres have a higher soil organic carbon increase in the no-practice scenario than the baseline conservation condition because of the higher fertilization rates, including manure application rates, used in the no-practice scenario to simulate the effects of nutrient management practices.

Table 16. Field-level effects of conservation practices on soil organic carbon for cultivated cropland in the Great Lakes Region

Model simulated outcome	Baseline conservation condition	No-practice scenario	Reduction due to practices	Percent reduction
Cropped acres (14.8 million acres)				
Average annual loss of carbon with wind and water erosion (pounds/acre)	179	198	19	10
Average annual change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)	-58	-97	39*	--
Land in long-term conserving cover (0.6 million acres)				
Average annual loss of carbon with wind and water erosion (pounds/acre)	73	128	56	44
Average annual change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)	317	-9	326*	--

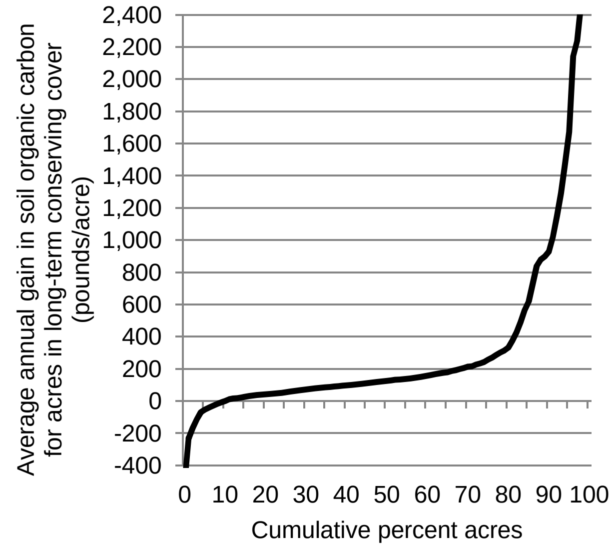
* Gain in soil organic carbon due to conservation practices.
Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text.
Note: Model simulation results for the baseline conservation condition are presented in appendix B for the Lake basins.

Land in long-term conserving cover

For land in long-term conserving cover, the annual change in soil organic carbon for the baseline conservation condition averages 317 pounds per acre per year (table 16). If these acres were still being cropped without any conservation practices, the annual average change in soil organic carbon would be a loss of 9 pounds per acre per year.

For these 593,000 acres, the gain in soil organic carbon averages 326 pounds per acre compared to a cropped condition without conservation practices. This is equivalent to a carbon dioxide emission reduction of 0.35 million U.S. tons of carbon dioxide for the region. However, the rate of emission reduction due to conservation practices varies considerably among acres in long-term conserving cover, as shown in figure 27.

Figure 27. Estimates of average annual gain in soil organic carbon due to conversion to long-term conserving cover in the Great Lakes Region



Note: About 10 percent of the acres in long-term conserving cover have decreases in annual carbon gain compared to a cropped condition. Biomass production under long-term conserving cover is typically nitrogen limited. The higher biomass production and resulting crop residue from the fertilization of cropped acres can exceed the carbon benefits of long-term conserving cover under some conditions.

Effects of Practices on Nitrogen Loss

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. In total, these sources provide about 134 pounds of nitrogen per acre per year for cropped acres in the Great Lakes Region (table 17). Model simulations show that about 72 percent of this (96 pounds per acre) is taken up by the crop and removed at harvest in the crop yield, on average, and the remainder is lost from the field through various pathways.

Baseline condition for cropped acres

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 47 pounds per acre. These nitrogen loss pathways are (fig. 28)—

- nitrogen lost due to volatilization associated primarily with fertilizer and manure application (average of 7 pounds per acre per year);
- nitrogen returned to the atmosphere through denitrification (average of 2.5 pounds per acre per year);
- nitrogen lost with windborne sediment (average of 5.3 pounds per acre per year);
- nitrogen lost with surface runoff, including nitrogen lost with waterborne sediment (average of 6.1 pounds per acre per year); and
- nitrogen loss in subsurface flow pathways (average of 25.8 pounds per acre per year).

The two pathways that impact water quality directly—surface water *and* subsurface flows (average of 31.9 pounds/acre per year)—account for 68 percent of the total nitrogen loss in this region. Most of the nitrogen loss in subsurface flows returns to surface water through drainage ditches, tile drains, natural seeps, and groundwater return flow.

Model simulation results showed that nitrogen loss to specific pathways varies from acre to acre, as shown in figures 29 and 30. However, loss of nitrogen in subsurface flows is the dominant loss pathway for 76 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 loss with waterborne sediment, windborne sediment, and through volatilization were each the dominant loss pathway for 7 to 8 percent of cropped acres. Nitrogen loss in surface water (soluble) and through denitrification were dominant loss pathways for less than 2 percent of the acres in this region.

Loss of nitrogen in subsurface flows can be quite high for some acres (fig. 29). Average annual losses of nitrogen in subsurface flows exceed 75 pounds per acre per year for the 6 percent of acres with the highest losses.

Acres receiving manure (19 percent of cropped acres) have higher nitrogen loss than acres not receiving manure. Total nitrogen loss for acres receiving manure was 69 pounds per acre per year, compared to 41 pounds per acre per year for acres not receiving manure (table 17). Losses were about the same for highly erodible land (17 percent of cropped acres) and non-highly erodible land in this region.

Figure 28. Average annual nitrogen loss by loss pathway, Great Lakes Region, baseline conservation condition

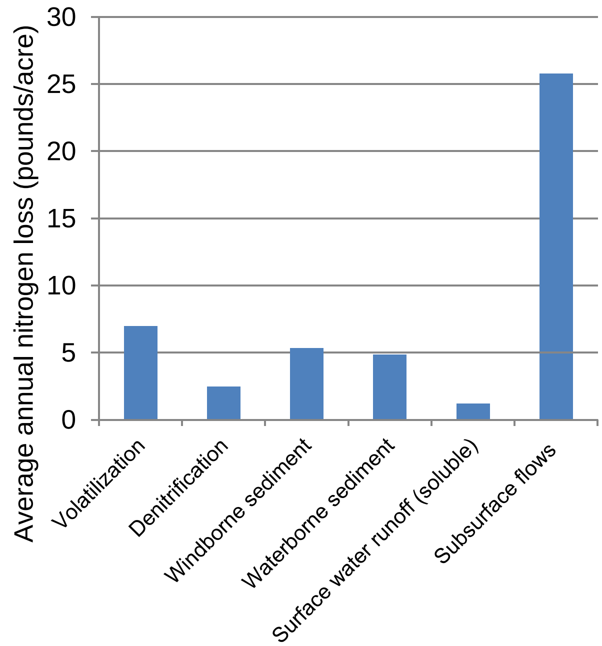


Figure 29. Cumulative distributions of average annual nitrogen lost through various loss pathways, Great Lakes Region, baseline conservation condition

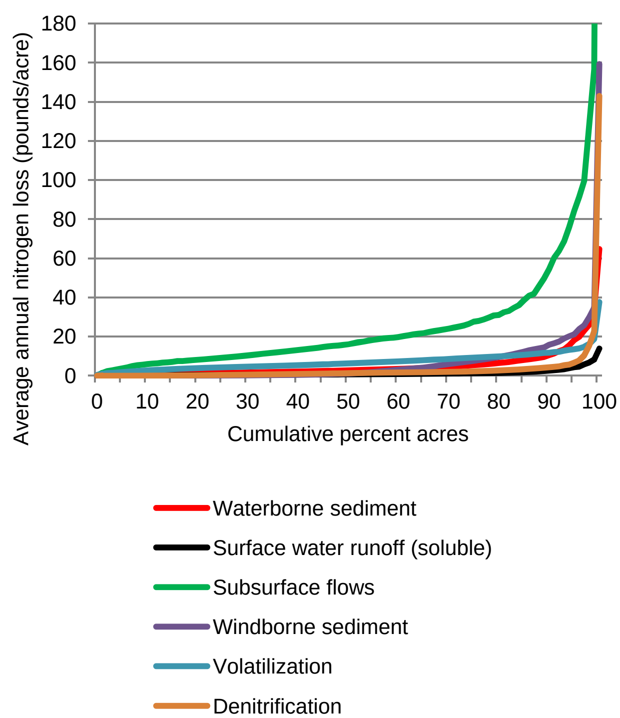
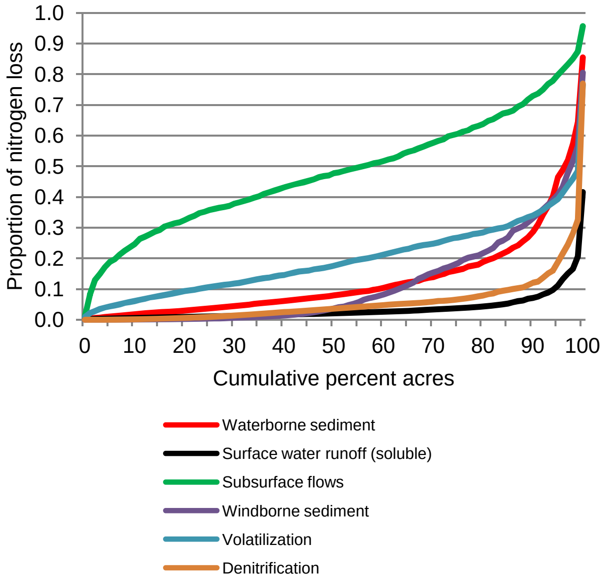


Figure 30. Cumulative distributions of proportions of nitrogen lost through six loss pathways, Great Lakes Region, baseline conservation condition



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.

Model simulations for the baseline conservation condition indicate that some cropped acres in the Great Lakes Region are much more susceptible to the effects of weather than other acres and lose much higher amounts of nitrogen (fig. 31). About 45 percent of the acres lose less than 40 pounds per acre per year through the various loss pathways under *all* weather conditions. About 13 percent of the acres, on the other hand, lose more than 100 pounds per acre in at least some years, and more than 50 pounds per acre in almost every year. In years with the most extreme weather, up to 5 percent of the acres lose over 180 pounds of nitrogen. Figure 31 also shows that nitrogen loss for the 20 percent of the cropped acres with the highest losses varies significantly from year to year when compared to the 40 percent with the lowest total nitrogen loss.

The *average annual* total nitrogen loss for the baseline is shown in figure 32. Acres with the highest nitrogen losses have the highest inherent vulnerability combined with inadequate nutrient management and runoff controls. About 57 percent of cropped acres lose less than 40 pounds per acre per year, while 6 percent lose more than 100 pounds per acre per year.

Table 17. Field-level effects of conservation practices on nitrogen sources and nitrogen loss pathways for cropped acres in the Great Lakes Region

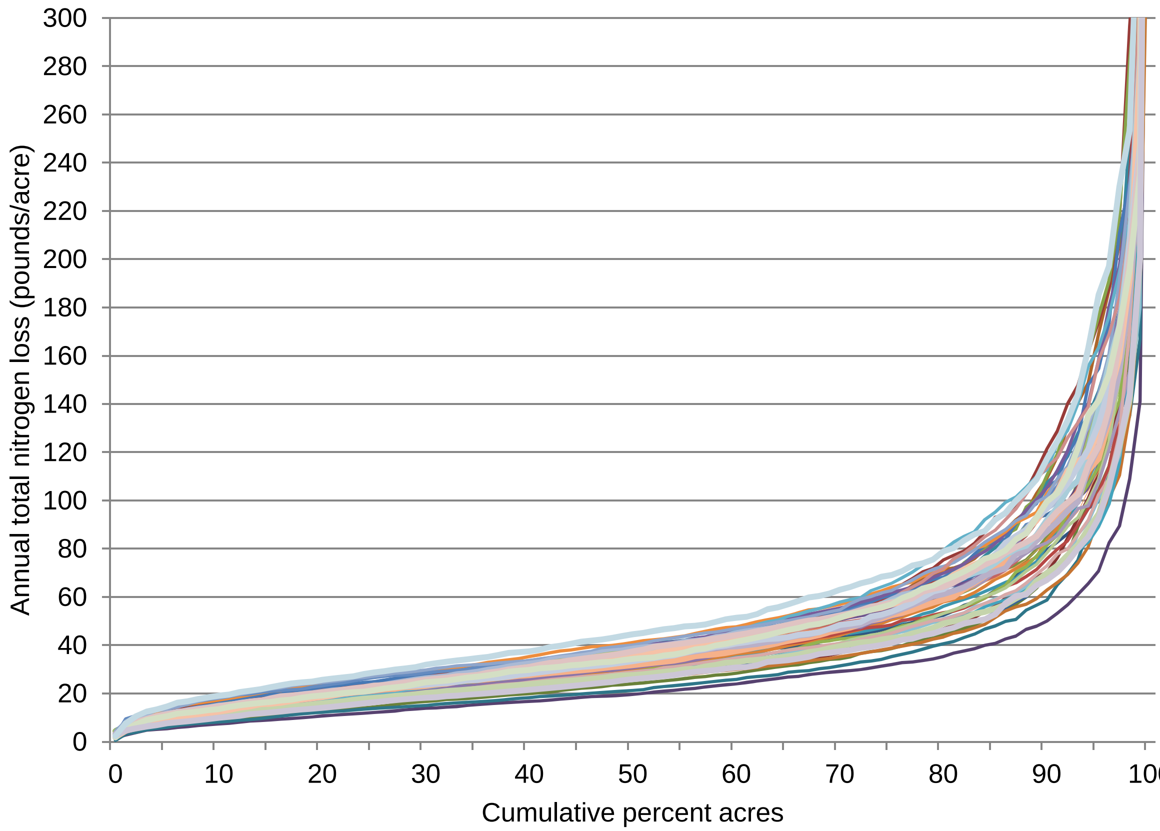
Model simulated outcome	Average annual values in pounds per acre: Baseline conservation condition	No-practice scenario	Reduction due to practices	Percent reduction
All cropped acres				
Nitrogen sources				
Atmospheric deposition	8.0	8.0	0.0	0
Bio-fixation by legumes	48.0	44.9	-3.1	-7
Nitrogen applied as commercial fertilizer and manure	77.5	102.5	24.9	24
All nitrogen sources	133.6	155.4	21.8	14
Nitrogen in crop yield removed at harvest	95.6	102.8	7.2*	7*
Nitrogen loss pathways				
Nitrogen loss by volatilization	7.0	6.5	-0.5**	-7**
Nitrogen loss through denitrification	2.5	2.6	0.2**	6**
Nitrogen lost with windborne sediment	5.3	7.8	2.5	32
Nitrogen loss with surface runoff, including waterborne sediment	6.1	10.6	4.5	43
Nitrogen loss with surface water (soluble)	1.2	4.2	3.0	71
Nitrogen loss with waterborne sediment	4.9	6.4	1.5	24
Nitrogen loss in subsurface flow pathways	25.8	37.0	11.2	30
Total nitrogen loss for all loss pathways	46.7	64.6	17.9	28
Change in soil nitrogen	-10.4	-13.4	-3.0	--
Highly erodible land (17 percent of cropped acres)				
All nitrogen sources	134	156	22.9	15
Total nitrogen loss for all loss pathways	48	68	20.5	30
Non-highly erodible land (83 percent of cropped acres)				
All nitrogen sources	134	155	21.6	14
Total nitrogen loss for all loss pathways	46	64	17.4	27
Acres with manure applied (19percent of cropped acres)				
All nitrogen sources	161	204	43.6	21
Total nitrogen loss for all loss pathways	69	108	38.4	36
Acres without manure applied (81 percent of cropped acres)				
All nitrogen sources	127	144	16.7	12
Total nitrogen loss for all loss pathways	41	55	13.2	24

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

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

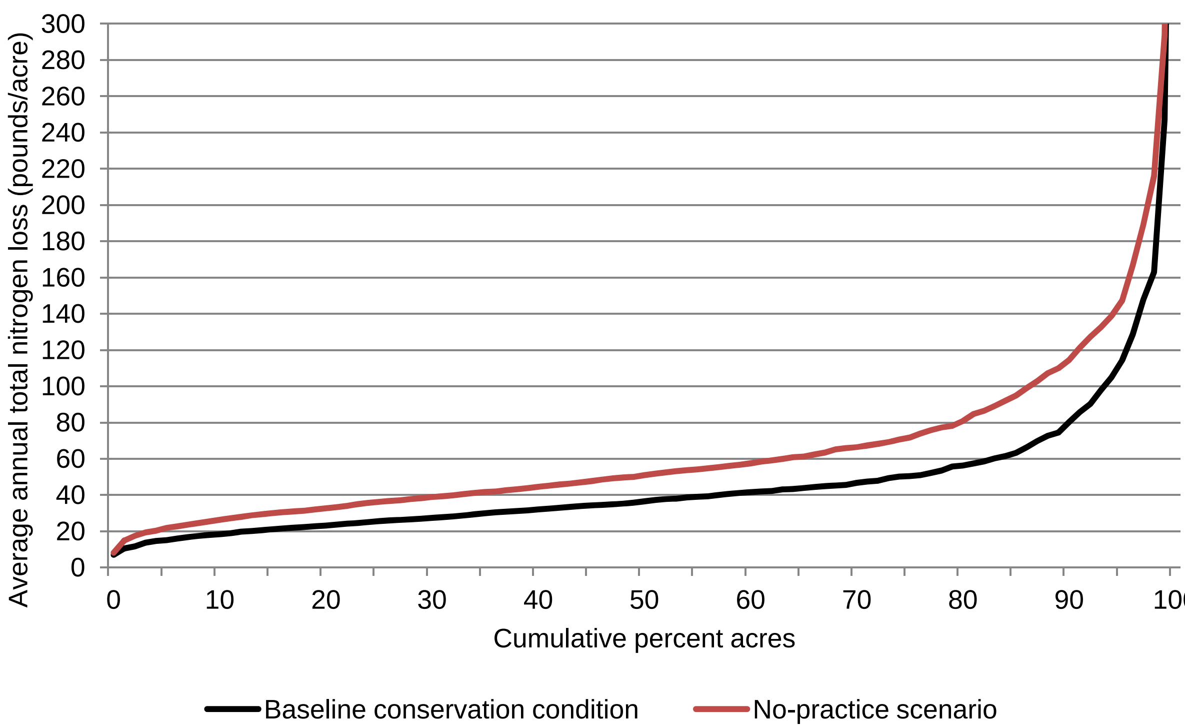
Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Model simulation results for the baseline conservation condition are presented in appendix B for the Lake basins.

Figure 31. Distribution of annual total nitrogen loss for each year of the 47-year model simulation, Great Lakes Region



Note: This figure shows how annual total nitrogen loss (pounds per acre per year) varied within the region and from year to year in the model simulation for cropped acres. Each of the 47 curves shown above represents a single year of data and shows how annual total nitrogen loss varied over the region in that year, starting with the acres with the lowest total nitrogen loss and increasing to the acres with the highest total nitrogen loss. The family of curves shows how annual total nitrogen loss varied from year to year. The average annual curve for the baseline is shown in figure 32 (below).

Figure 32. Estimates of average annual total nitrogen loss for cropped acres in the Great Lakes Region



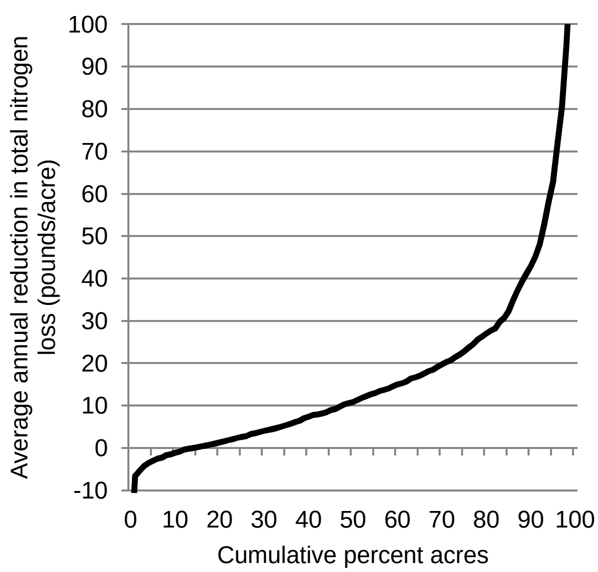
Effects of conservation practices on cropped acres

Model simulations show that the conservation practices in use in the region have reduced total nitrogen loss from cropped acres by an average of 18 pounds per acre per year, representing a 28 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. 32).

The effects of conservation practices vary from acre to acre (fig. 33). About half of the acres have average annual reductions in total nitrogen loss below 11 pounds per acre. In contrast, about 17 percent of the acres have reduced total nitrogen loss by an average of over 30 pounds per acre per year. These are acres with higher levels of treatment and often higher levels of nitrogen use in the no-practice scenario.

Figure 33 also shows that about 14 percent of the acres have an *increase* in total nitrogen loss due to conservation practice use. Most of these increases are small; only 3 percent of the acres have increases of more than 4 pounds per acre. This result primarily occurs on soils with relatively high soil nitrogen content and generally with low slopes where the surface water runoff is re-directed to subsurface flow by soil erosion control practices. The higher volume of water moving through the soil profile extracts more nitrogen from the soil than under conditions without conservation practices. Cropping systems that include legumes can have a higher soil nitrogen stock in the baseline conditions because legumes produce proportionately less biofixation of nitrogen under the higher fertilization rates simulated in the no-practice scenario.

Figure 33. Estimates of average annual reduction in total nitrogen loss due to the use of conservation practices on cropped acres in the Great Lakes Region



Note: See text for discussion of conditions that result in lower total nitrogen loss in the no-practice scenario than in the baseline conservation condition for 14 percent of the acres.

Nitrogen lost with surface runoff. Model simulations show that, on average, nitrogen lost with surface runoff has been reduced 43 percent due to use of conservation practices in the region (table 17). Without conservation practices, about 18 percent of the cropped acres would have nitrogen lost with surface runoff in excess of an average of 15 pounds per acre per year, compared to only 7 percent of the acres in the baseline conservation condition (fig. 34). Figure 35 shows that about 8 percent of the cropped acres have reductions in nitrogen lost with surface runoff greater than 10 pounds per acre due to conservation practice use. Figure 35 also shows, however, that about 71 percent of the acres have reductions less than 5 pounds per acre due to conservation practices.

Figure 34 Estimates of average annual nitrogen lost with surface runoff (including waterborne sediment) for cropped acres in the Great Lakes Region

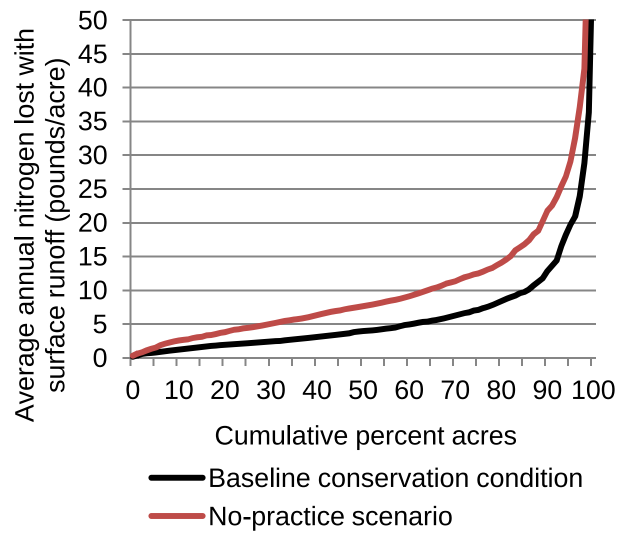
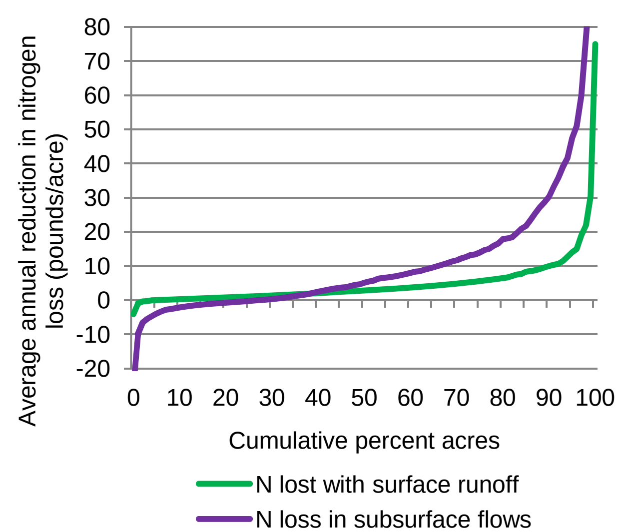


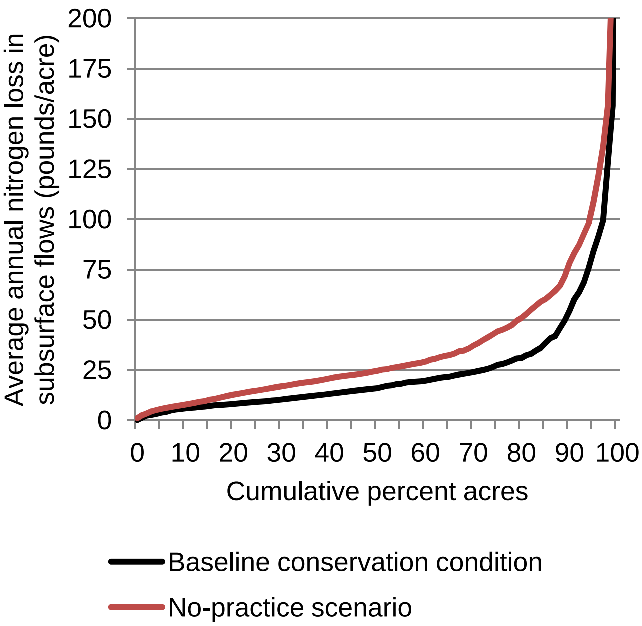
Figure 35. Estimates of average annual reduction in nitrogen lost with surface runoff and reduction in nitrogen loss in subsurface flows due to the use of conservation practices on cropped acres in the Great Lakes Region



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

Nitrogen loss in subsurface flows. Conservation practices are effective in reducing nitrogen loss in subsurface flows on many acres in this region, but make little difference on other acres and even result in small increases in nitrogen loss in subsurface flows for 25 percent of cropped acres (figs. 35 and 36). (Increases in nitrogen loss in subsurface flows are represented in figure 35 as negative reductions.) On average, conservation practices have reduced nitrogen loss in subsurface flows from 37 pounds per acre without practices to 26 pounds per acre with practices, representing an average reduction of 11 pounds per acre per year (30-percent reduction) (table 17). Figure 35 shows that reductions in average annual nitrogen loss in subsurface flows exceed 30 pounds per acre for 10 percent of the cropped acres, but are less than 5 pounds per acre for about half of the acres.

Figure 36. Estimates of average annual nitrogen loss in subsurface flows for cropped acres in the Great Lakes Region



The increases in nitrogen loss in subsurface flows due to conservation practices on 25 percent of the cropped acres (fig. 35) are largely due to relatively weak nutrient management practices on acres with erosion control treatment. A portion of the reduction in nitrogen lost with surface runoff is re-routed to subsurface loss pathways, resulting in gains or only small reductions in nitrogen loss in subsurface flows. This re-routing of surface water runoff to subsurface flow pathways results in additional nitrogen being leached from the soil, diminishing and sometimes offsetting the overall positive effects of conservation practices on total nitrogen loss.

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

Tradeoffs in Conservation Treatment

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

- Terraces and conservation tillage are planned to solve a serious water erosion problem. However, in some areas there may be concern about 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.
- A nutrient management plan reduces the amount of manure added to a field to reduce the loss of nutrients to surface or groundwater. However, the reduction in organic material added to the field may reduce the soil organic matter or reduce the rate of change in soil organic matter.
- Figure 33 shows that about 14 percent of the acres have an increase in total nitrogen loss due to conservation practice use. This result occurs primarily on soils with relatively high soil nitrogen content and generally low slopes where the surface water runoff is re-directed to subsurface flow by soil erosion control practices. The higher volume of water moving through the soil profile extracts more nitrogen from the soil than under conditions without conservation practices. For these fields, the nutrient management component of a farmer's conservation plan would need to be enhanced to reduce or eliminate the negative effects of soil erosion control practices on nitrogen loss.

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

Nitrogen Use, Crop Uptake, and Loss from Farm Fields Vary Among Lake Basins

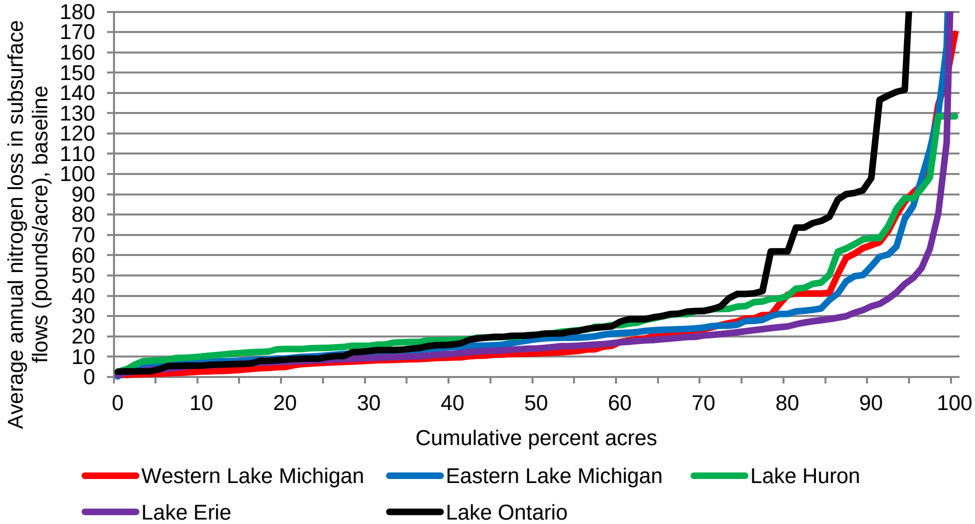
Within the Great Lakes Region, average annual nitrogen loss from fields is highest in the Lake Ontario basin and lowest in the Lake Erie basin. Although nitrogen sources are highest in the Lake Erie basin, field-level losses are lower because nitrogen removed from the field with crop harvest is also higher. Nitrogen sources are about the same in the basins other than Lake Erie, but field-level losses are higher in the Lake Ontario and Lake Huron basins in part because of lower crop yields. (See appendix B, table B2.)

Average Annual Values in Pounds Per Acre, 2003–06 Baseline

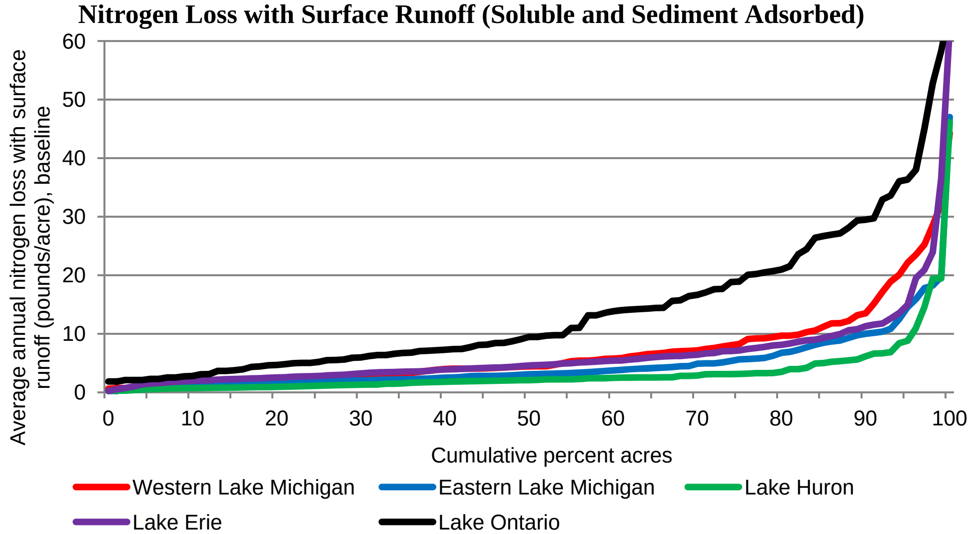
	Western Lake Michigan	Eastern Lake Michigan	Lake Huron	Lake Erie	Lake Ontario
All nitrogen sources*	129	128	126	143	128
Nitrogen in crop yield removed at harvest	94	93	85	105	79
Total nitrogen loss for all loss pathways	41	50	56	38	69
Nitrogen loss with surface runoff	7	5	3	6	14
Nitrogen loss in subsurface flow pathways	24	27	31	19	48
Other losses**	10	19	22	13	8
Change in soil nitrogen	-9	-17	-17	-2	-21

*Includes atmospheric deposition, bio-fixation by legumes, and nitrogen applied as commercial fertilizer and manure.
**Includes nitrogen loss by volatilization, through denitrification, and with windborne sediment.
Notes: Results for Lake Superior are not reported because of small sample size. Not included in the table is nitrogen bound up in surface residue.

Nitrogen Loss in Subsurface Flow Pathways



Nitrogen Loss with Surface Runoff (Soluble and Sediment Adsorbed)



Land in long-term conserving cover

Total nitrogen loss has been reduced by about 77 percent on the 0.6 million acres in long-term conserving cover, compared to conditions that would be expected had the acres remained in crops. Converting cropped acres to long-term conserving cover is very effective in reducing total nitrogen loss, as demonstrated in figure 37 and table 18, although the reductions are much higher for some acres than others. Conversion of cropped acres to long-term conserving cover in the region has reduced nitrogen loss in subsurface flows from these acres from an average loss of 33.3 pounds per acre per year to about 1.6 pounds per acre per year, a reduction of 31.7 pounds per acre per year.

Figure 37. Estimates of average annual total nitrogen loss for land in long-term conserving cover in the Great Lakes Region

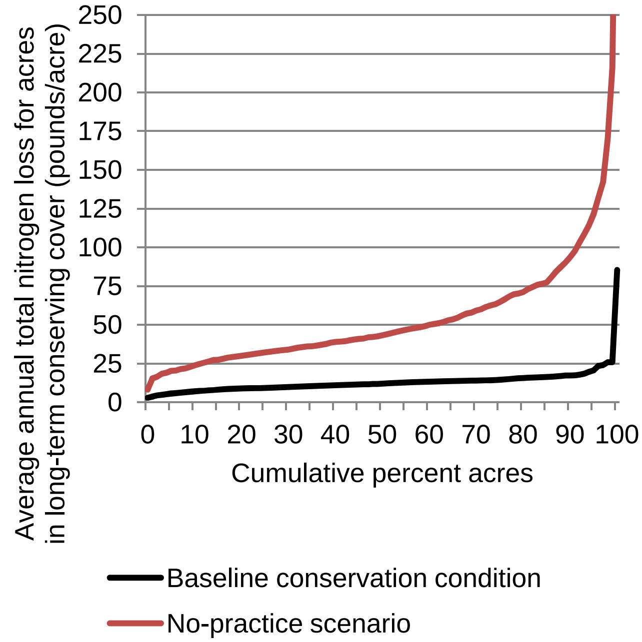


Table 18. Effects of conservation practices on nitrogen sources and nitrogen loss pathways for land in long-term conserving cover (0.6 million acres), Great Lakes Region

Model simulated outcome	Baseline conservation condition	No-practice scenario	Reduction due to practices	Percent reduction
	Average annual values in pounds per acre			
Nitrogen sources				
Atmospheric deposition	8.1	8.1	0.0	0
Bio-fixation by legumes	11.0	46.3	35.3	76
Nitrogen applied as commercial fertilizer and manure	0.0	95.8	95.8	100
All nitrogen sources	19.0	150.1	131.1	87
Nitrogen in crop yield removed at harvest	1.0*	99.0	98.0	99
Nitrogen loss pathways				
Nitrogen loss by volatilization	8.8	6.6	-2.2	-33
Nitrogen loss through denitrification	1.7	2.5	0.8	32
Nitrogen lost with windborne sediment	0.0	0.2	0.2	100
Nitrogen loss with surface runoff, including waterborne sediment	0.6	11.7	11.1	95
Nitrogen loss with surface water (soluble)	0.2	3.8	3.6	95
Nitrogen loss with waterborne sediment	0.4	7.9	7.6	95
Nitrogen loss in subsurface flow pathways	1.6	33.3	31.7	95
Total nitrogen loss for all pathways	12.6	54.3	41.6	77
Change in soil nitrogen	4.3	-4.5	-8.8	--

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

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

Effects of Practices on Phosphorus Loss

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

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 Great Lakes Region, about 21 pounds per acre of phosphorus were applied as commercial fertilizer or in manure to cropped acres, on average, in each year of the model simulation (table 19). About 70 percent of the phosphorus applied is taken up by the crop and removed at harvest—15 pounds per acre per year, on average.

Total phosphorus loss for all loss pathways averaged 3.25 pounds per acre per year in the baseline conservation condition (table 19). These phosphorus loss pathways are—

- phosphorus lost with windborne sediment (average of 1.13 pounds per acre per year);
- phosphorus lost with waterborne sediment (average of 0.95 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 1.14 pounds per acre per year); and
- soluble phosphorus that percolates through the soil profile into the groundwater (average of 0.03 pound per acre per year).

On average, approximately equal amounts of phosphorus are lost in the three principal loss pathways in the Great Lakes Region— attached to soil particles in waterborne sediment (29 percent of total loss), soluble phosphorus lost to surface water (35 percent), and phosphorus loss with windborne sediment (35 percent) (fig. 38, table 19). A very small amount of soluble phosphorus is lost through percolation into groundwater—1 percent of the total phosphorus loss. The percent of phosphorus lost in each loss pathway varies from acre to acre, as shown in figure 39 for cropped acres.

Soluble phosphorus loss with surface water runoff and lateral flow (including discharge to drainage tiles, ditches, and seeps) was the dominant loss pathway for 39 percent of cropped acres. (The dominant loss pathway was determined for each sample point as the pathway with the highest loss.) Phosphorus lost with windborne sediment is the dominant loss pathway for 35 percent of cropped acres, and phosphorus lost with waterborne sediment is the dominant loss pathway for 26 percent.

As shown previously for nitrogen, phosphorus losses are much higher for acres receiving manure (5.9 pounds per acre) than for acres that did not receive manure (2.6 pounds per acre) (table 19). This difference is directly related to the amount of phosphorus applied, which was much higher for acres receiving manure than for acres not receiving manure. Phosphorus losses are also higher for highly erodible land than for non-highly erodible land.

About 70 percent of the acres lose less than 4 pounds per acre per year through the various loss pathways under *all* weather conditions (figs. 40 and 41). About 15 percent of the acres, on the other hand, lose more than 8 pounds per acre in at least some years.

Figure 38. Estimates of average annual phosphorus lost through various loss pathways, Great Lakes Region , baseline conservation condition

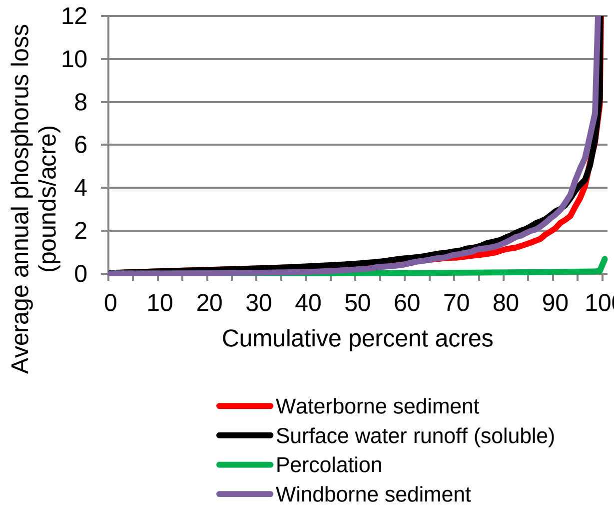


Figure 39. Cumulative distributions of the proportion of phosphorus lost through various loss pathways, Great Lakes Region, baseline conservation condition

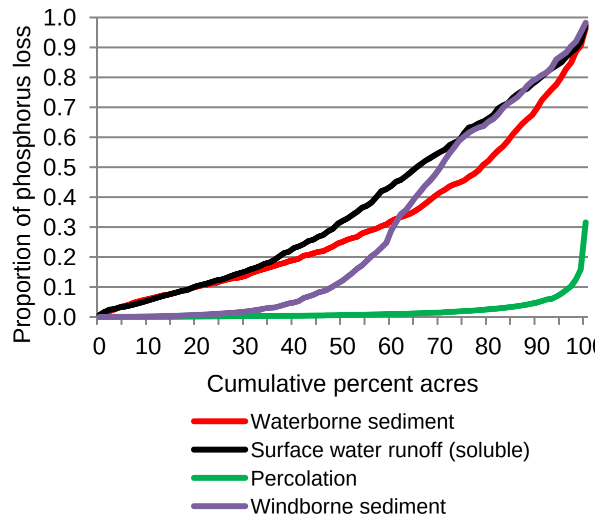


Table 19. Field-level effects of conservation practices on phosphorus sources and phosphorus loss pathways for cultivated cropland in the Great Lakes Region

Model simulated outcome	Average annual values in pounds per acre			
	Baseline conservation condition	No-practice scenario	Reduction due to practices	Percent reduction
Cropped acres (14.8 million acres)				
Phosphorus sources				
Phosphorus applied as commercial fertilizer and manure	20.7	27.3	6.6	24
Phosphorus in crop yield removed at harvest	14.65	15.54	0.89	6
Phosphorus loss pathways				
Phosphorus lost with windborne sediment	1.13	2.08	0.95	46
Phosphorus lost to surface water (sediment attached and soluble)*	2.09	3.25	1.16	36
Soluble phosphorus lost to surface water*	1.14	1.59	0.46	29
Phosphorus loss with waterborne sediment	0.95	1.65	0.70	42
Soluble phosphorus loss to groundwater	0.03	0.03	0.00	0
Total phosphorus loss for all loss pathways	3.25	5.36	2.11	39
Change in soil phosphorus	2.75	6.45	3.70	--
Highly erodible land (17 percent of cropped acres)				
Phosphorus applied as commercial fertilizer and manure	22.0	27.7	5.7	21
Total phosphorus loss for all loss pathways	4.2	6.9	2.70	39
Non-highly erodible land (83 percent of cropped acres)				
Phosphorus applied as commercial fertilizer and manure	20.5	27.3	6.8	25
Total phosphorus loss for all loss pathways	3.1	5.0	1.99	39
Acres with manure applied (19 percent of cropped acres)				
Phosphorus applied as commercial fertilizer and manure	34.7	42.7	8.1	19
Total phosphorus loss for all loss pathways	5.9	8.9	2.97	33
Acres without manure applied (81 percent of cropped acres)				
Phosphorus applied as commercial fertilizer	17.5	23.7	6.3	26
Total phosphorus loss for all loss pathways	2.6	4.5	1.91	42
Land in long-term conserving cover (0.6 million acres)				
Phosphorus sources				
Phosphorus applied as commercial fertilizer and manure	0.0	26.3	26.3	100
Phosphorus in crop yield removed at harvest	0.37**	14.88	14.51	98
Phosphorus loss pathways				
Phosphorus lost with windborne sediment	0.00	0.05	0.05	100
Phosphorus lost to surface water (sediment attached and soluble)*	0.34	3.45	3.11	90
Soluble phosphorus lost to surface water*	0.30	1.61	1.31	81
Phosphorus loss with waterborne sediment	0.04	1.83	1.80	98
Soluble phosphorus loss to groundwater	0.08	0.04	-0.04	-100
Total phosphorus loss for all loss pathways	0.41	3.53	3.12	88
Change in soil phosphorus	-0.90	7.94	8.83	--

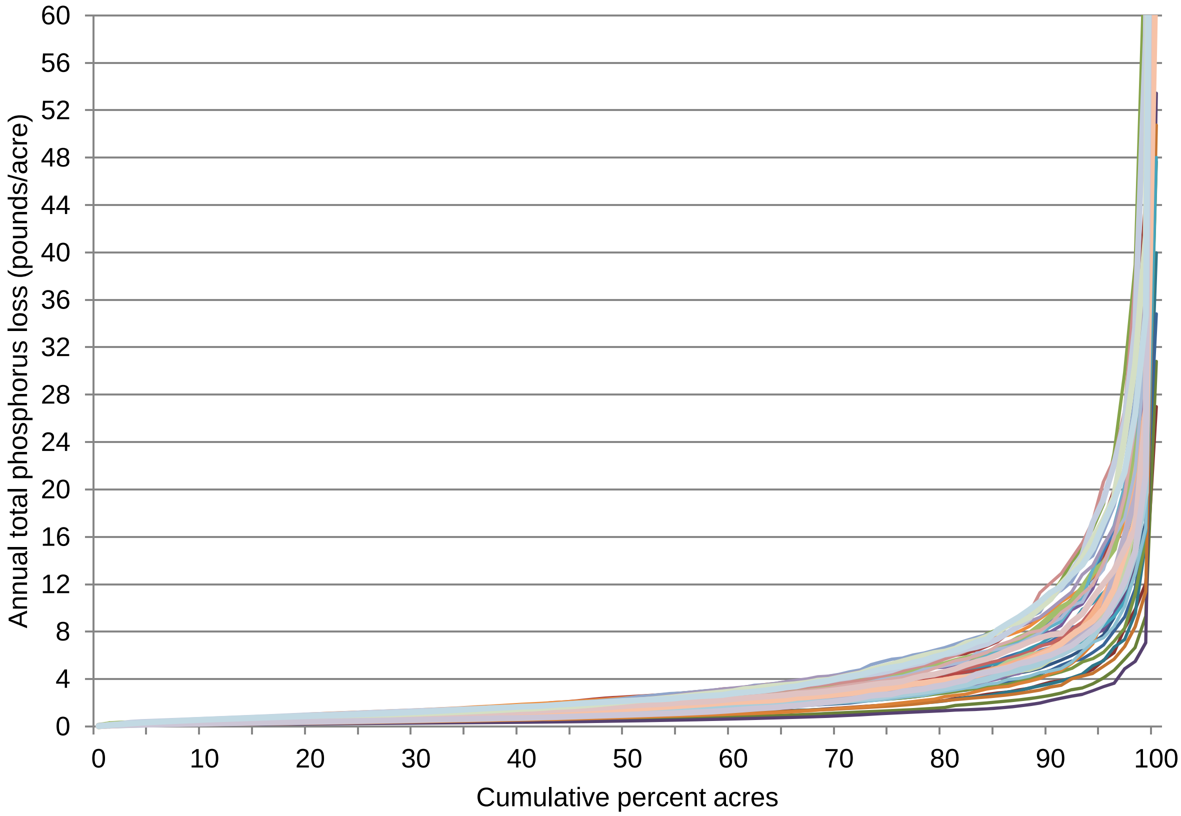
* Soluble phosphorus lost to surface water includes phosphorus in water moving laterally within the soil into drainage systems (tile and surface drainage) and natural seeps.

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

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

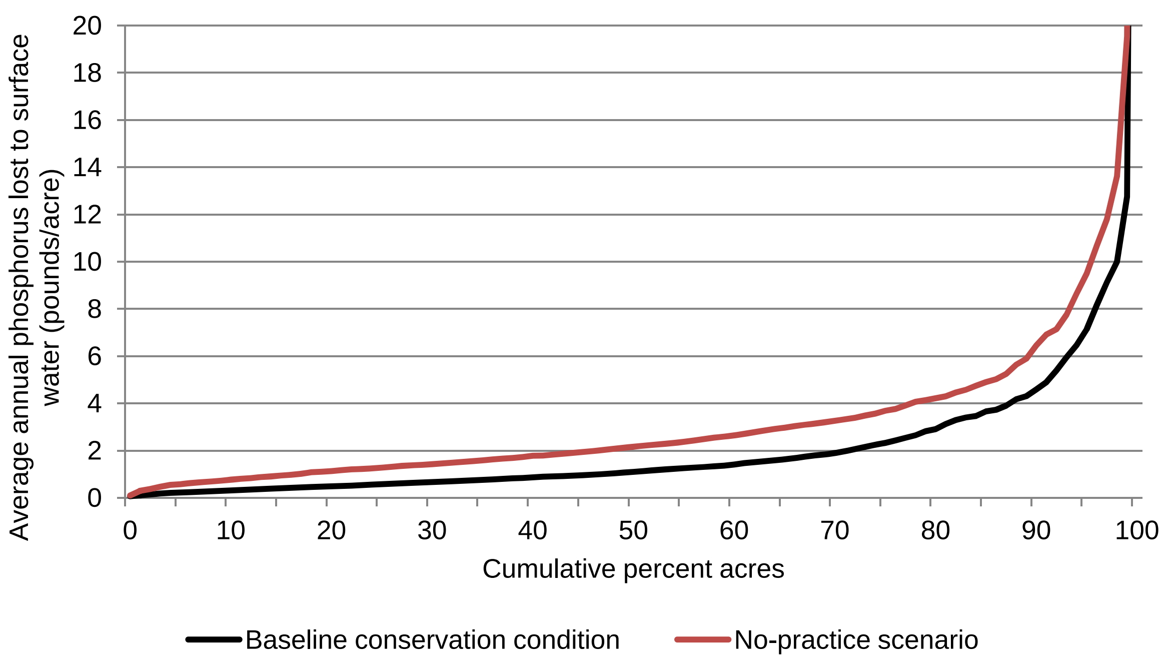
Note: Model simulation results for the baseline conservation condition are presented in appendix B for the Lake basins.

Figure 40. Distribution of annual total phosphorus loss for each year of the 47-year model simulation, Great Lakes Region



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

Figure 41. Estimates of average annual phosphorus lost to surface water (sediment attached and soluble)*for cropped acres in the Great Lakes Region



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

Phosphorus Use and Loss from Farm Fields Vary Among Lake Basins

Within the Great Lakes Region, average annual phosphorus loss from fields is highest in the Lake Ontario and Lake Huron basins. Phosphorus lost to surface water (phosphorus lost with waterborne sediment and soluble phosphorus) averaged 5.8 pounds per acre per year in the Lake Ontario basin, compared to averages ranging from 1.2 to 2.1 pounds per acre per yearin the other basins. Phosphorus application rates were significantly higher in the Lake Ontario basin than in other basins, in part because of a higher frequency of manure applications, while phosphorus removed from the field with crop harvest was about the same as in other basins. Total phosphorus loss for the Lake Huron basin is high because of loss of phosphorus with windborne sediment, which averaged 3 pounds per acre per year in that basin. (See appendix B, table B2.)

The proportion of total phosphorus lost as soluble phosphorus was higher in the Lake Erie and Lake Ontario basins than in the other basins, averaging 53 percent for the Lake Erie basin and 41 percent for the Lake Ontario basin compared to a range of 18 percent to 35 percent for the other basins.

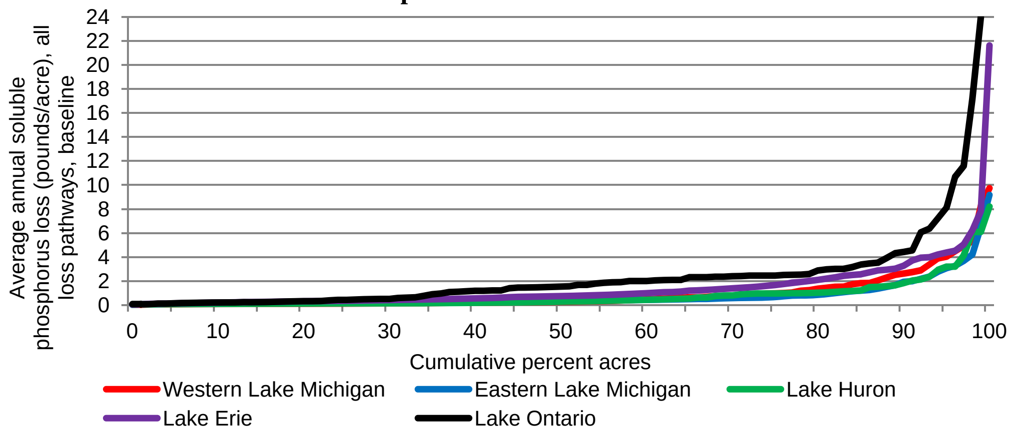
Average Annual Values in Pounds Per Acre, 2003–06 Baseline

	Western Lake Michigan	Eastern Lake Michigan	Lake Huron	Lake Erie	Lake Ontario
Phosphorus applied as commercial fertilizer or manure*	20.2	17.9	19.1	21.2	29.7
Phosphorus in crop yield removed at harvest	13.5	15.1	12.9	15.9	12.9
Total phosphorus loss for all loss pathways	2.6	3.3	4.2	2.5	5.9
Soluble phosphorus lost to surface water*	0.9	0.7	0.7	1.3	2.5
Phosphorus loss with waterborne sediment	1.1	0.6	0.4	0.8	3.3
Phosphorus lost with windborne sediment	0.5	2.0	3.0	0.4	0.1
Change in soil phosphorus	4.0	-0.5	2.0	2.7	10.8

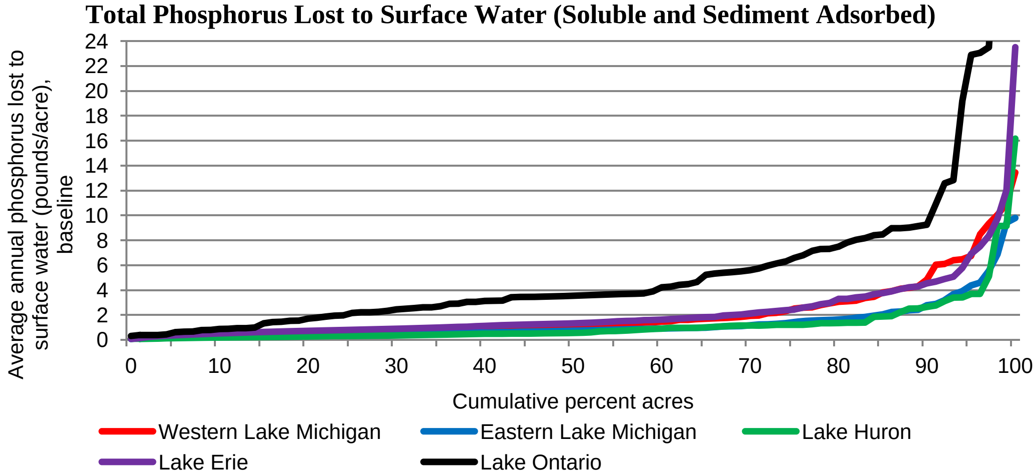
* Soluble phosphorus lost to surface water includes soluble phosphorus in surface water runoff and soluble phosphorus in water moving laterally within the soil into drainage systems (tile and surface drainage) and natural seeps.

Notes: Results for Lake Superior are not reported because of small sample size. Not included in the table is phosphorus bound up in surface residue.

Soluble Phosphorus Lost To Surface Water



Total Phosphorus Lost to Surface Water (Soluble and Sediment Adsorbed)



Effects of conservation practices on cropped acres

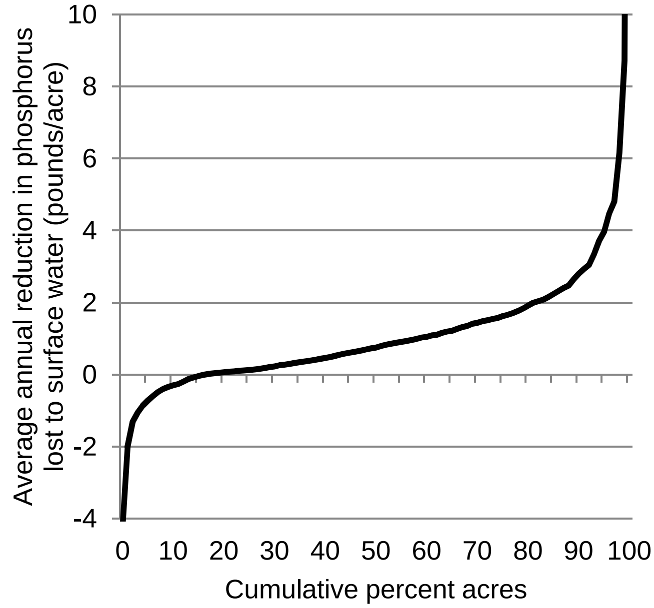
Conservation practices have reduced total phosphorus lost to surface water for cropped acres by 36 percent, reducing the average loss from 3.25 pounds per acre per year if conservation practices were not in use to 2.09 pounds per acre per year for the baseline conservation condition (table 19). The effects of conservation practices on phosphorus lost to surface water (soluble and sediment attached) are shown in figures 41 and 42 for cropped acres. With the conservation practices in use as represented by the baseline conservation condition, about 12 percent of cropped acres exceed 4 pounds per acre per year, on average. Without those practices in use, phosphorus lost to surface water would exceed 4 pounds per acre for 22 percent of the acres (fig. 41).

The effects of conservation practices on phosphorus lost to surface water vary considerably throughout the Great Lakes Region, as shown in figure 42. Reductions due to practices are less than 1 pound per acre for 58 percent of the cropped acres. At the high end, reductions exceed 3 pounds per acre for about 8 percent of the acres.

Land in long-term conserving cover

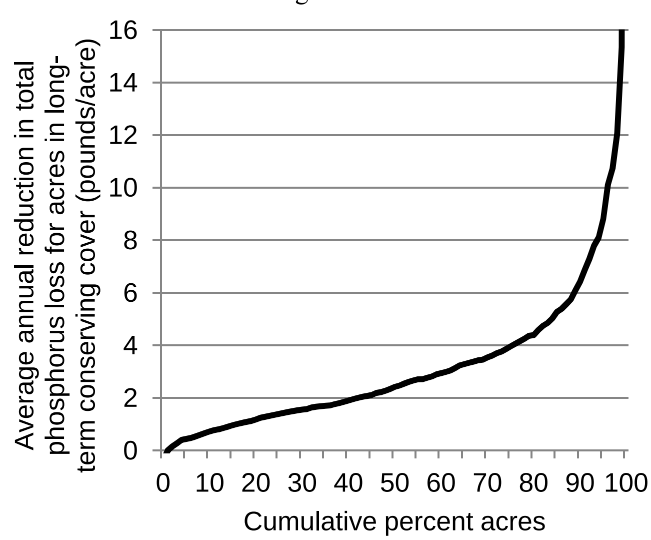
For land in long-term conserving cover, total phosphorus loss is 88 percent less than it would have been if crops had been grown and no conservation practices used, reducing total phosphorus loss by 3.1 pounds per acre per year, on average (table 19). Reductions vary among the acres in the region; reductions are less than 2 pounds per acre for about 45 percent of the acres in long-term conserving cover, and greater than 6 pounds per acre for about 10 percent (fig. 43).

Figure 42. Estimates of average annual reduction in phosphorus lost to surface water (sediment attached and soluble) due to conservation practices on cropped acres in the Great Lakes Region



Note: As shown in figure 16, about 14 percent of cropped acres had less surface water runoff in the no-practice scenario than the baseline, resulting in negative reductions. These negative reductions in runoff explain, in part, the negative reductions in phosphorus loss with runoff. Gains in surface water runoff when conservation practices are applied can occur on soils with low to moderate potential for runoff when: (1) excessive nutrient application rates in the no-practice scenario produces more biomass, lowering soil moisture and thus reducing runoff, or (2) tillage of the surface soil in the no-practice scenario reduces surface compaction and crusting, producing temporary surface roughness that in turn reduces runoff. Reduced tillage n these kinds of landscapes can also cause soluble phosphorus to concentrate near or on the soil surface, where it is more vulnerable to surface runoff.

Figure 43. Estimates of average annual reduction in total phosphorus loss due to conversion to long-term conserving cover in the Great Lakes Region



Effects of Practices on Pesticide Residues and Environmental Risk

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

Baseline condition for pesticide loss

The APEX model tracks the mass loss of pesticides dissolved in surface water runoff, adsorbed to sediment lost through water erosion, and dissolved in subsurface flow pathways.[16] The distribution of losses through each of these three pathways is contrasted in figure 44. All three pathways are important in the transport of pesticide residues from fields, but the majority of pesticide lost from fields is dissolved in surface water runoff, on average. Pesticides dissolved in surface water runoff accounted for 63 percent of the total mass loss, waterborne sediment accounted for about 21 percent, and pesticides in subsurface flows accounted for 15 percent.

The dominant loss pathway for 61 percent of cropped acres was pesticides dissolved in surface water runoff. Waterborne sediment was the dominant pesticide loss pathway for 23 percent of the acres, and subsurface flows were the dominant pesticide loss pathway for 10 percent of the acres. The remaining 6 percent of the acres had no pesticide loss.

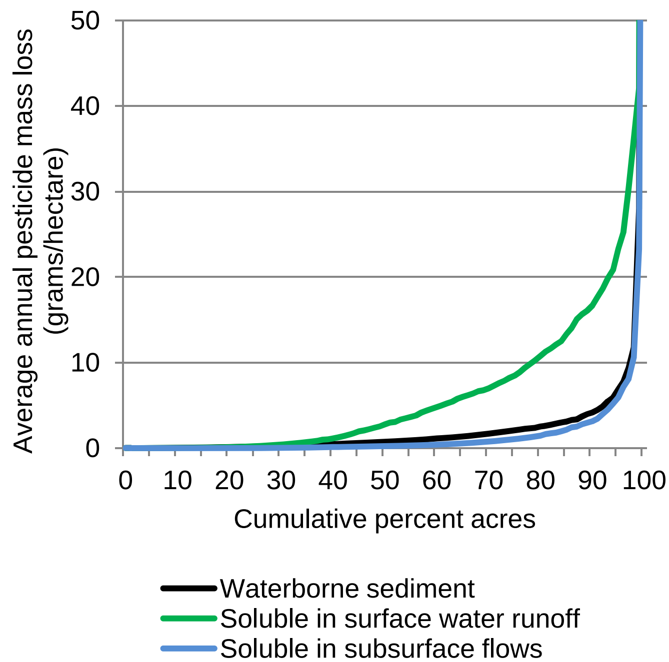
The average annual amount of pesticide lost from farm fields in the Great Lakes Region is about 11 grams of active ingredient per hectare per year (table 20).[17] As was observed for sediment and nutrient loss, the majority of pesticide loss occurs on a minority of acres within the Great Lakes Region (fig. 44). The median loss is only 5.0 grams per hectare.

In the model simulations, the pesticide applied in the largest amount throughout the region was glyphosate at 23 percent of the total weight of pesticides applied, followed closely by atrazine at 21 percent (table 21). The herbicides acetochlor and S-metolachlor represented 10 and 11 percent, respectively, of the total weight of pesticides applied. These four pesticides accounted for 64 percent of the pesticides applied in the region, by weight.

The most common pesticide residues lost from farm fields are atrazine (33 percent of total mass loss), S-metolachlor (13 percent), and acetochlor (8 percent) (table 21). Glyphosate, pendimethalin, sulfentrazone, metolachlor and metam-sodium each represented 4 to 5 percent of the total mass loss. These eight pesticides account for 76 percent of all pesticide residues lost from fields in the model simulations for the Great Lakes Region.

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

Figure 44. Estimates of average annual pesticide loss (mass loss of all pesticides combined) for three loss pathways, Great Lakes Region, baseline conservation condition



---

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

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

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

Model simulated outcome	Baseline conservation condition	No-practice scenario	Reduction due to practices	Percent reduction
Pesticide sources				
Average annual amount of pesticides applied (grams of active ingredient/hectare)	1,667	1,922	255	13%
Pesticide loss				
Average annual mass loss of pesticides for all pathways (grams of active ingredient/hectare)	11	14	3	23%
Edge-of-field pesticide risk indicator				
Average annual surface water pesticide risk indicator for aquatic ecosystems	1.89	2.59	0.69	27%
Average annual surface water pesticide risk indicator for humans	0.44	0.59	0.16	26%
Average annual groundwater pesticide risk indicator for humans	0.10	0.14	0.03	25%

Note: It was assumed that no pesticides were applied to land in long-term conserving cover and there were no data on residual pesticides in the soil for these acres; thus, the assessment of the effects of this practice on pesticide loss was not done.
Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Model simulation results for the baseline conservation condition are presented in appendix B for the Lake basins.

Table 21. Dominant pesticides applied in model simulations and contributing to losses, Great Lakes Region

Pesticide (active ingredient name)	Pesticide type	Percent of total applied in the region
Pesticide application*		
Glyphosate, isopropylamine salt	Herbicide	23
Atrazine	Herbicide	21
S-Metolachlor	Herbicide	11
Acetochlor	Herbicide	10
Metam-sodium	Multi-purpose	5
Pendimethalin	Herbicide	3
Metolachlor	Herbicide	2
EPTC	Herbicide	2
Mancozeb	Fungicide	2
Alachlor	Herbicide	2
Chlorothalonil	Fungicide	2
Chlorpyrifos	Insecticide	1
2,4-D, 2-ethylhexyl ester	Herbicide	1
Simazine	Herbicide	1
Total		87
		Percent of total pesticide loss in the region**
Pesticide loss from farm fields*		
Atrazine	Herbicide	33
S-Metolachlor	Herbicide	13
Acetochlor	Herbicide	8
Glyphosate, isopropylamine salt	Herbicide	5
Pendimethalin	Herbicide	4
Sulfentrazone	Herbicide	4
Metolachlor	Herbicide	4
Metam-sodium	Multi-purpose	4
Triclopyr	Herbicide	3
Mancozeb	Fungicide	3
Dimethenamide-P	Herbicide	2
Simazine	Herbicide	2
Sulfur	Fungicide	1
Alachlor	Herbicide	1
2,4-D 2-ethylhexyl ester	Herbicide	1
Chlorothalonil	Fungicide	1
Total		89

* Pesticides not listed each represented less than 1 percent of the total. Percents may not add to total due to rounding.
** Includes loss of pesticides dissolved in surface water runoff, adsorbed to sediment loss from water erosion, and dissolved in subsurface flow pathways.

Effects of conservation practices on pesticide residues and risk

Management practices that reduce the potential for loss of pesticides from farm fields consist of a combination of Integrated 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. Use of conservation practices has reduced the loss of pesticides (summed over all pesticides) by an average of 3 grams of active ingredient per hectare per year, a 23-percent reduction from the 14 grams per hectare for the no-practice scenario (table 20).

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

Pesticide risk indicators were therefore developed to represent risk at the edge of the field (bottom of soil profile for groundwater). These edge-of-field risk indicators are based on the ratio of pesticide concentrations in water leaving the field to safe concentrations (toxicity thresholds) for each pesticide. As such, these risk indicators do not have units. The pesticide risk indicators were developed so that the relative risk for individual pesticides could be aggregated over the 151 pesticides included in the model for the Great Lakes Region.[18]

Risk indicator values of less than 1 are considered “safe” because the concentration is below the toxicity threshold for exposure at the edge of the field.[19]

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

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

Atrazine was the dominant pesticide contributing to all three risk indicators (table 22). Based on the model simulations, the edge-of-field risk indicator for atrazine exceeded 1 for 34 percent of the cropped acres for risk to aquatic ecosystems, 8 percent of the cropped acres for surface water risk to humans, and 1 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 45 shows that for most years the overall risk for aquatic ecosystems is low, in part because of the conservation practices in use. But in some years the edge-of-field concentrations can be high relative to "safe" thresholds for some acres. The pesticide risk indicator for aquatic ecosystems averaged 1.89 over all years and cropped acres (table 20) for the baseline conservation condition. (The 1.89 value indicates that pesticide concentrations in water leaving cropped fields in the Great Lakes Region are, on average, 1.89 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 0.72 (fig. 46).

---

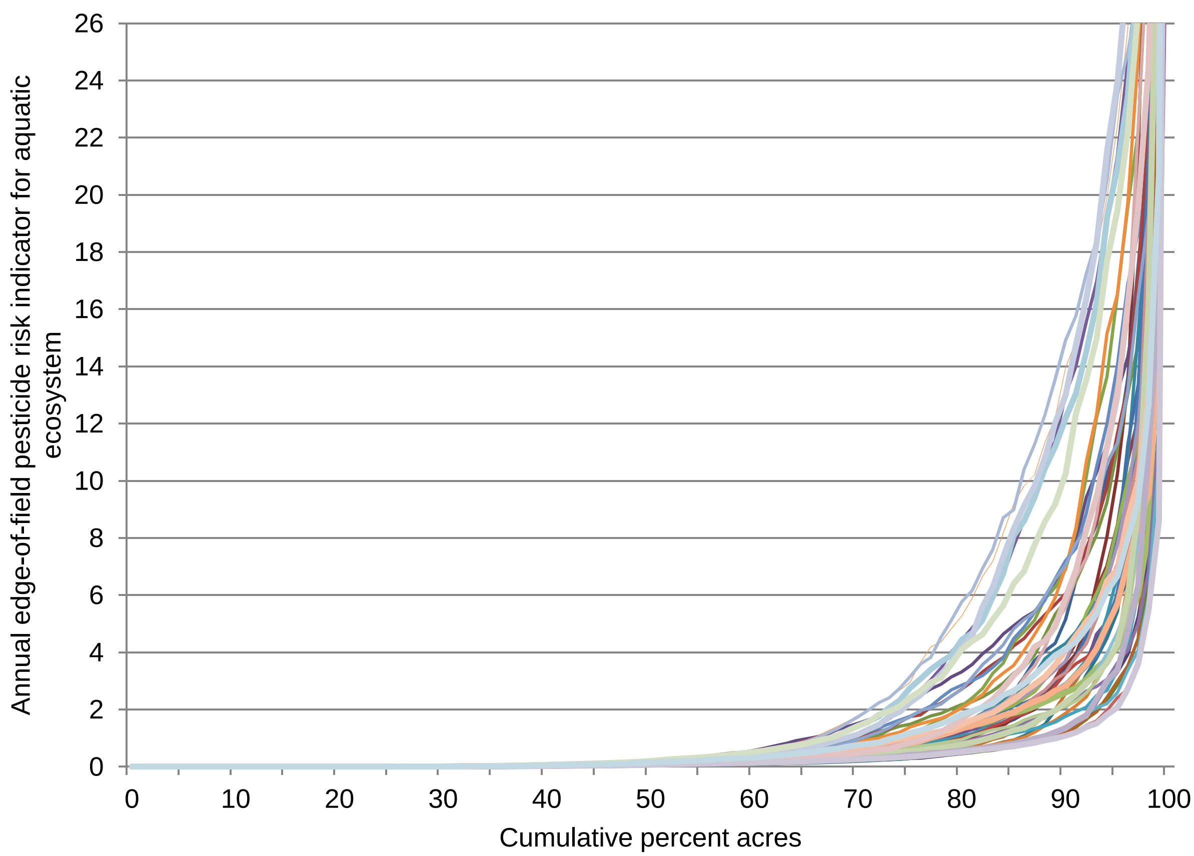
[18] For a complete documentation of the development of the pesticide risk indicators, see “Pesticide risk indicators used in the CEAP cropland modeling,” found at http://www.nrcs.usda.gov/technical/nri/ceap.

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

Table 22. Dominant pesticides determining edge-of-field environmental risk, Great Lakes Region

Pesticide (active ingredient name)	Pesticide type	Percent of cropped acres in the region with average annual edge-of-field risk indicator greater than 1
Risk indicator for aquatic ecosystem		
Atrazine	Herbicide	34
Acetochlor	Herbicide	7
2,4-D 2-ethylhexyl ester	Herbicide	4
Sulfentrazone	Herbicide	3
Metolachlor	Herbicide	3
Chlorpyrifos	Insecticide	1
Phostebupirim	Insecticide	<1
Risk indicator for humans, surface water		
Atrazine	Herbicide	8
Alachlor	Herbicide	<1
Fipronil	Miticide	<1
Risk indicator for humans, groundwater		
Atrazine	Herbicide	1
Metam-sodium	Multi-purpose	<1

Figure 45. 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, Great Lakes Region



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

The pesticide risk indicators for humans were much lower, averaging 0.44 for surface water and 0.10 for groundwater (table 20). The median values are 0.15 for surface water and 0.08 for groundwater. Only about 11 percent of the cropped acres have an average annual edge-of-field surface water pesticide risk indicator for humans greater than 1 (fig. 47), and only 1 percent have an average annual bottom-of-the-rootzone groundwater pesticide risk indicator greater than 1.

The use of conservation practices in the Great Lakes Region has reduced the pesticide risk indicators by 25 to 27 percent (table 20), averaged over all years, all pesticides, and all cropped acres.

Figure 48 shows the distribution of the reductions in the two pesticide risk indicators due to conservation practices. Significant risk reductions for aquatic ecosystems occur on about 25 percent of the acres, while significant risk reductions for humans occur on only about 5 percent of the acres. The benefits of conservation practices were significant for both aquatic risks and human risks on the acres that had those risks, but aquatic risks were more widespread than human risks so conservation practices have greater total benefit for aquatic ecosystems than for human drinking water.

Figure 46. Estimates of average annual edge-of-field surface water pesticide risk indicator for aquatic ecosystem in the Great Lakes Region

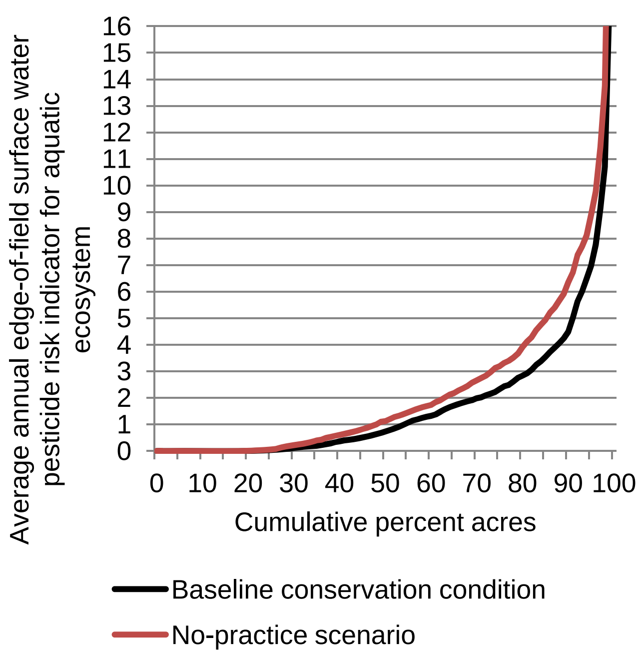


Figure 47. Estimates of average annual edge-of-field surface water pesticide risk indicator for humans in the Great Lakes Region

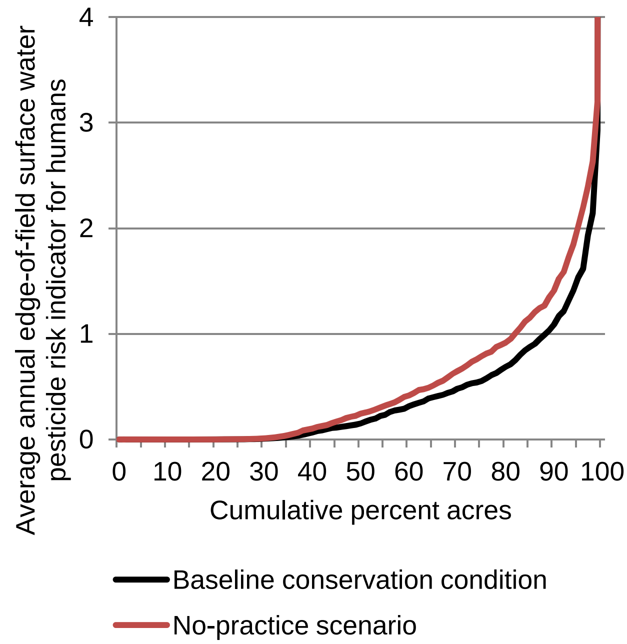
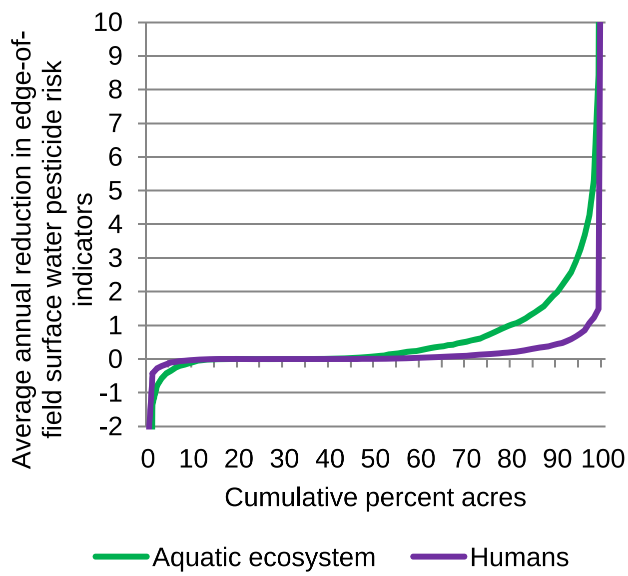


Figure 48. Estimates of average annual reductions in the edge-of-field surface water pesticide risk indicators for aquatic ecosystems in the Great Lakes Region



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

Chapter 5
Assessment of Conservation Treatment Needs

The adequacy of conservation practices in use in the Great Lakes region was evaluated to identify remaining conservation treatment needs for controlling wind erosion, 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 Great Lakes Region indicate that—

- *19 percent of cropped acres (2.8 million acres) have a **high** level of need for additional conservation treatment,*
- *34 percent of cropped acres (5.0 million acres) have a **moderate** level of need for additional conservation treatment, and*
- *47 percent of cropped acres (6.9 million 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. Five resource concerns were evaluated for the Great Lakes Region:

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

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

Adequate conservation treatment consists of combinations of conservation practices that treat the specific inherent vulnerability factors associated with each field. Not all acres require the same level of conservation treatment. Acres with a high level of inherent vulnerability require more treatment than less vulnerable acres to reduce field-level losses to acceptable levels. Acres with characteristics such as steeper slopes and soil types that promote surface water runoff are more vulnerable to sediment and nutrient losses beyond the edge of the field. Acres that are essentially flat with 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.

Under-treated 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 under-treated acres.

Conservation Treatment Levels

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 Great Lakes Region.

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 49. A high level of water erosion control treatment is in use on about 29 percent of cropped acres, primarily on non-highly erodible land. About 63 percent of cropped acres have a moderate or low level of conservation treatment for water erosion control, including the majority of highly erodible land.

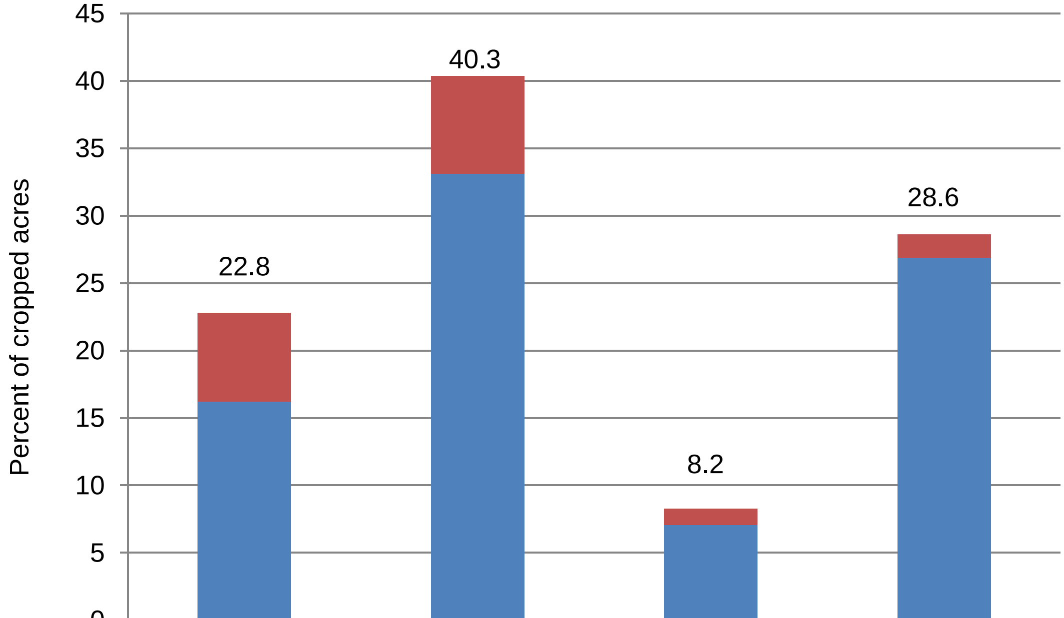
For nitrogen loss with surface runoff, conservation treatment levels were defined by a combination of structural practices, residue and tillage management practices, and nitrogen management practices, as defined in figure 50. A high level of treatment for nitrogen runoff is in use on only 5 percent of cropped acres. The bulk of cropped acres—80 percent--have combinations of practices that indicate a moderately high or moderate level of treatment. About 15 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 51. A high level of treatment for phosphorus runoff is in use on 7 percent of the acres. About 70 percent of cropped acres have combinations of practices that indicate a moderately high or moderate level of treatment. About 23 percent of cropped acres have a low level of phosphorus management.

The nitrogen management level presented in figure 9 (see chapter 3) was used to evaluate the adequacy of conservation treatment for nitrogen loss in subsurface flows. A high level of treatment for nitrogen loss in subsurface flows is in use on 18 percent of the acres. About 73 percent of cropped acres have combinations of practices that indicate a moderately high or moderate level of treatment. Only 9 percent of cropped acres have a low level of nitrogen management.

For wind erosion, a combination of structural practices and tillage intensity was used to evaluate the adequacy of conservation treatment, as defined in figure 52. A high level of treatment for wind erosion is in use on 3 percent of the acres (fig. 52), and 32 percent of the acres have a moderately high level of treatment. About 65 percent of the acres have a moderate or low level of treatment for controlling wind erosion.

Figure 49. Percent of cropped acres at four conservation treatment levels for water erosion control in the baseline conservation condition, Great Lakes Region



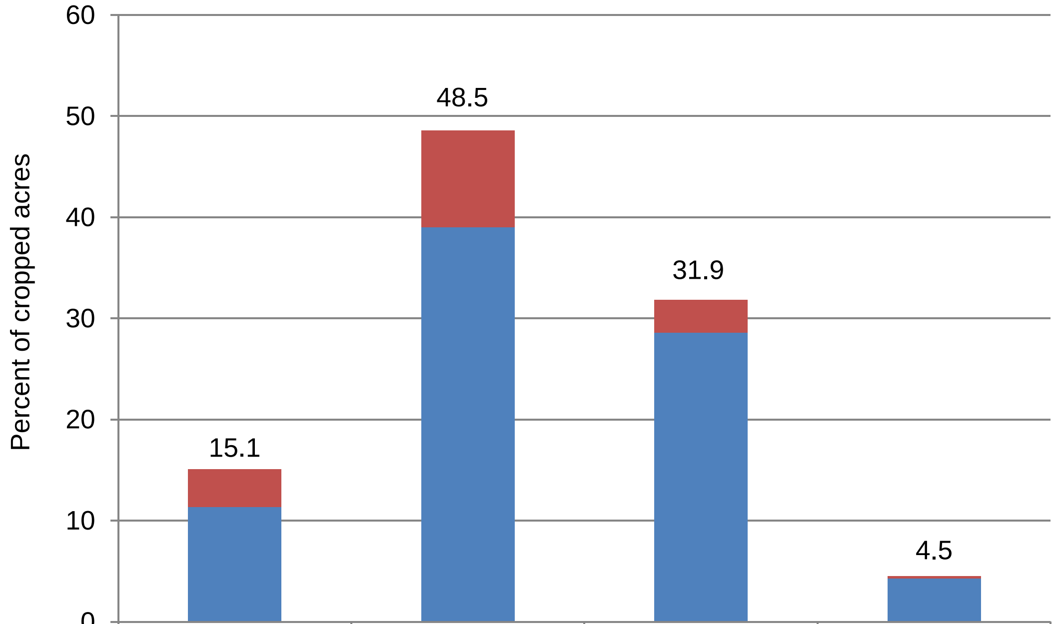
	Low	Moderate	Moderately high	High
HEL	6.6	7.2	1.2	1.7
Non-HEL	16.2	33.1	7.0	26.9

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

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

Note: About 17 percent of cropped acres in the Great Lakes Region is highly erodible land.

Figure 50 Percent of cropped acres at four conservation treatment levels for nitrogen runoff control in the baseline conservation condition, Great Lakes Region



	Low	Moderate	Moderately high	High
HEL	3.7	9.5	3.3	0.2
Non-HEL	11.4	39.0	28.6	4.3

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

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

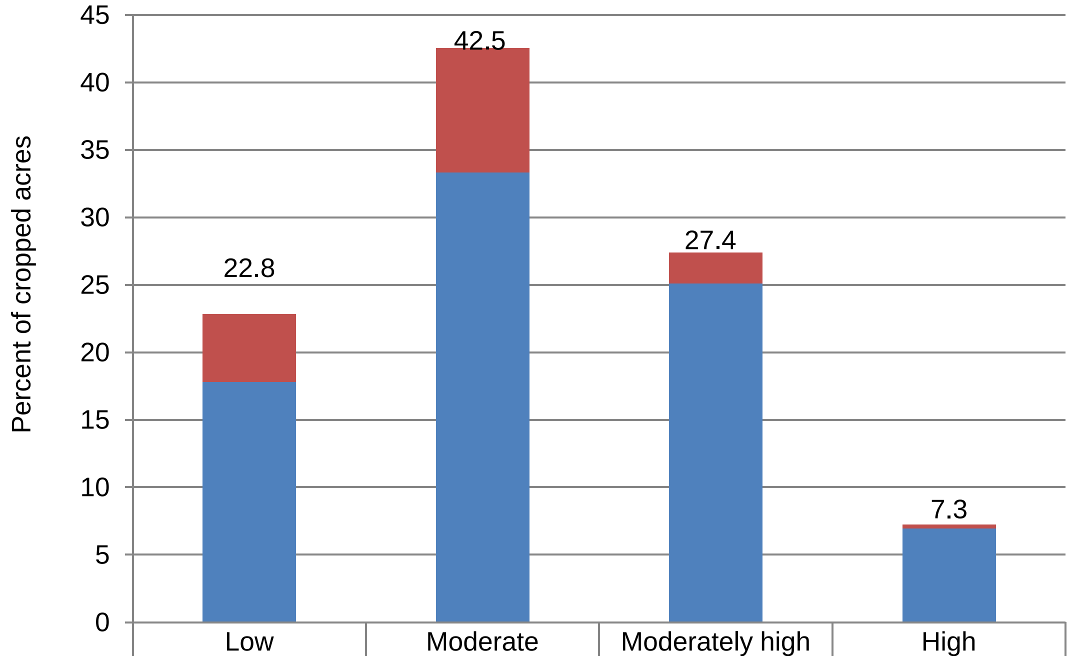
- **High treatment**: Sum of residue and tillage management score and nitrogen management score is equal to 8. (High treatment level for both structural practices and nitrogen management practices).
- **Moderately high treatment**: Sum of scores equal to 6 or 7.
- **Moderate treatment**: Sum of scores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

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

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

Note: About 17 percent of cropped acres in the Great Lakes Region is highly erodible land.

Figure 51 Percent of cropped acres at four conservation treatment levels for phosphorus runoff control in the baseline conservation condition, Great Lakes Region



	Low	Moderate	Moderately high	High
HEL	5.0	9.2	2.3	0.3
Non-HEL	17.8	33.3	25.1	7.0

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

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

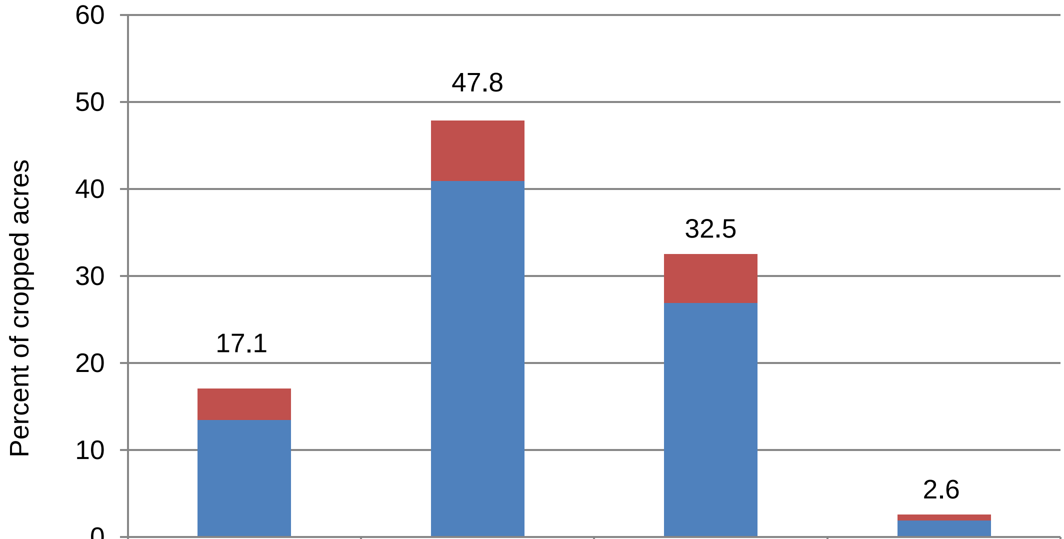
- **High treatment**: Sum of residue and tillage management score and phosphorus management score is equal to 8. (High treatment level for both structural practices and phosphorus management practices).
- **Moderately high treatment**: Sum of scores equal to 6 or 7.
- **Moderate treatment**: Sum of scores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

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

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

Note: About 17 percent of cropped acres in the Great Lakes Region is highly erodible land.

Figure 52. Percent of cropped acres at four conservation treatment levels for wind erosion management, baseline conservation condition, Great Lakes Region



	Low	Moderate	Moderately high	High
HEL	3.6	6.9	5.6	0.7
Non-HEL	13.5	40.9	26.9	1.9

Criteria were derived using a combination of structural practices for wind erosion control and residue and tillage management. Criteria for four levels of treatment are:

- **High treatment**: *All crops* meet tillage intensity criteria for either no-till or mulch till and at least one wind erosion control structural practice is in use.
- **Moderately high treatment**: A*ll crops* meet tillage intensity criteria for either no-till or mulch till without any wind erosion control structural practice or *average annual* tillage intensity meets criteria for mulch till or no-till and a wind erosion control structural practice is in use.
- **Moderate treatment**: A*verage annual* tillage intensity meets criteria for mulch till or no-till without any wind erosion control structural practice in use.
- **Low treatment**: No wind erosion control structural practices and *average annual* tillage intensity meets criteria for mulch till or no-till.

Note: About 17 percent of cropped acres in the Great Lakes Region is highly erodible land.

Inherent Vulnerability Factors

Not all acres require the same level of conservation treatment because of differences in inherent vulnerabilities due to soils and climate. Inherent vulnerability factors for surface runoff include soil properties that promote surface water runoff and erosion—soil hydrologic group, slope, and 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. Inherent vulnerability factors for wind erosion include precipitation, slope, and the wind erosion equation I-factor.

Soil runoff, leaching, and wind erosion 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 53, followed by the spatial distribution of the soil runoff potential within the Great Lakes region in figure 54. The criteria and spatial distribution for the soil leaching potential are presented in figures 55 and 56. The criteria for the wind erosion potential are presented in figure 57.

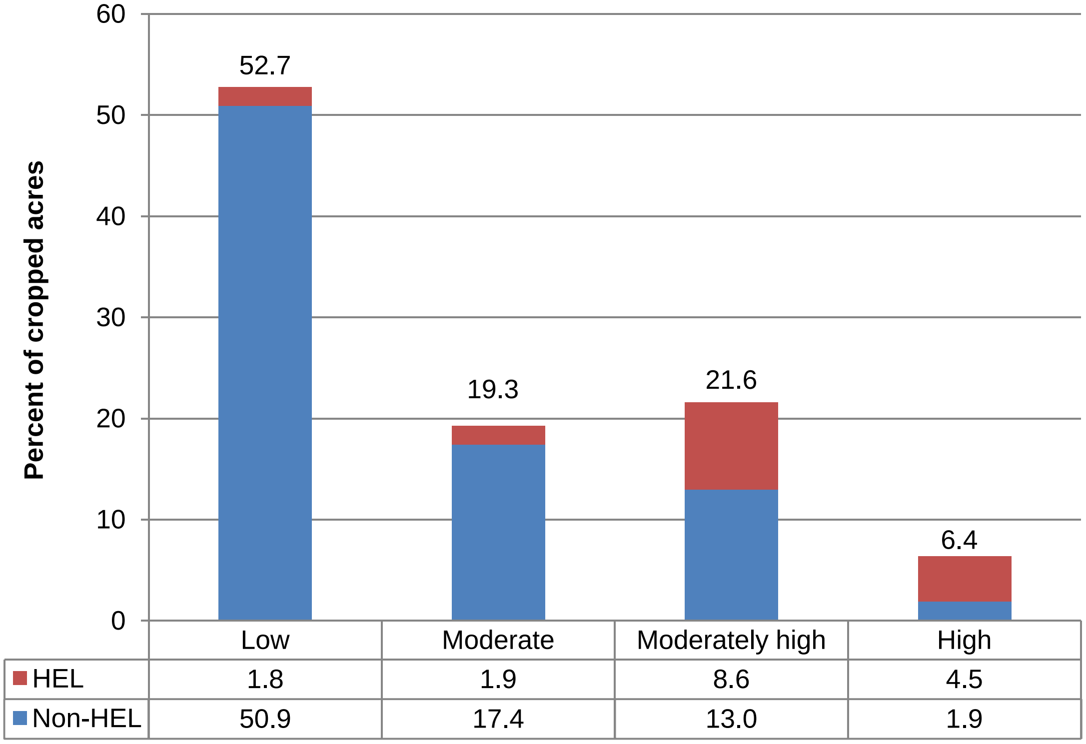
The maps show the vulnerability potentials for all soils and land uses in the region. For the assessment of conservation treatment needs, however, only the vulnerability potentials for cropped acres were used.

Cropped acres in the Great Lakes Region are a mix of vulnerable and non-vulnerable acres. About 53 percent of cropped acres in the Great Lakes Region have a low soil runoff potential (fig. 53). Only 6 percent of the acres have a high soil runoff potential, consisting mostly of highly erodible land, and 22 percent have a moderately high soil runoff potential.

About 15 percent of the cropped acres in the region have a high soil leaching potential (fig. 55), and 15 percent have a moderately high soil leaching potential. About 50 percent have a moderate soil leaching potential. About 20 percent of cropped acres have a low soil leaching potential in this region.

Less than 10 percent of cropped acres in this region have an inherent potential for wind erosion based on soil properties and precipitation (fig. 57). About 9 percent have a moderate or moderately high level of wind erosion potential. Less than 1 percent have a high potential for wind erosion.

Figure 53. Soil runoff potential for cropped acres in the Great Lakes Region



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:

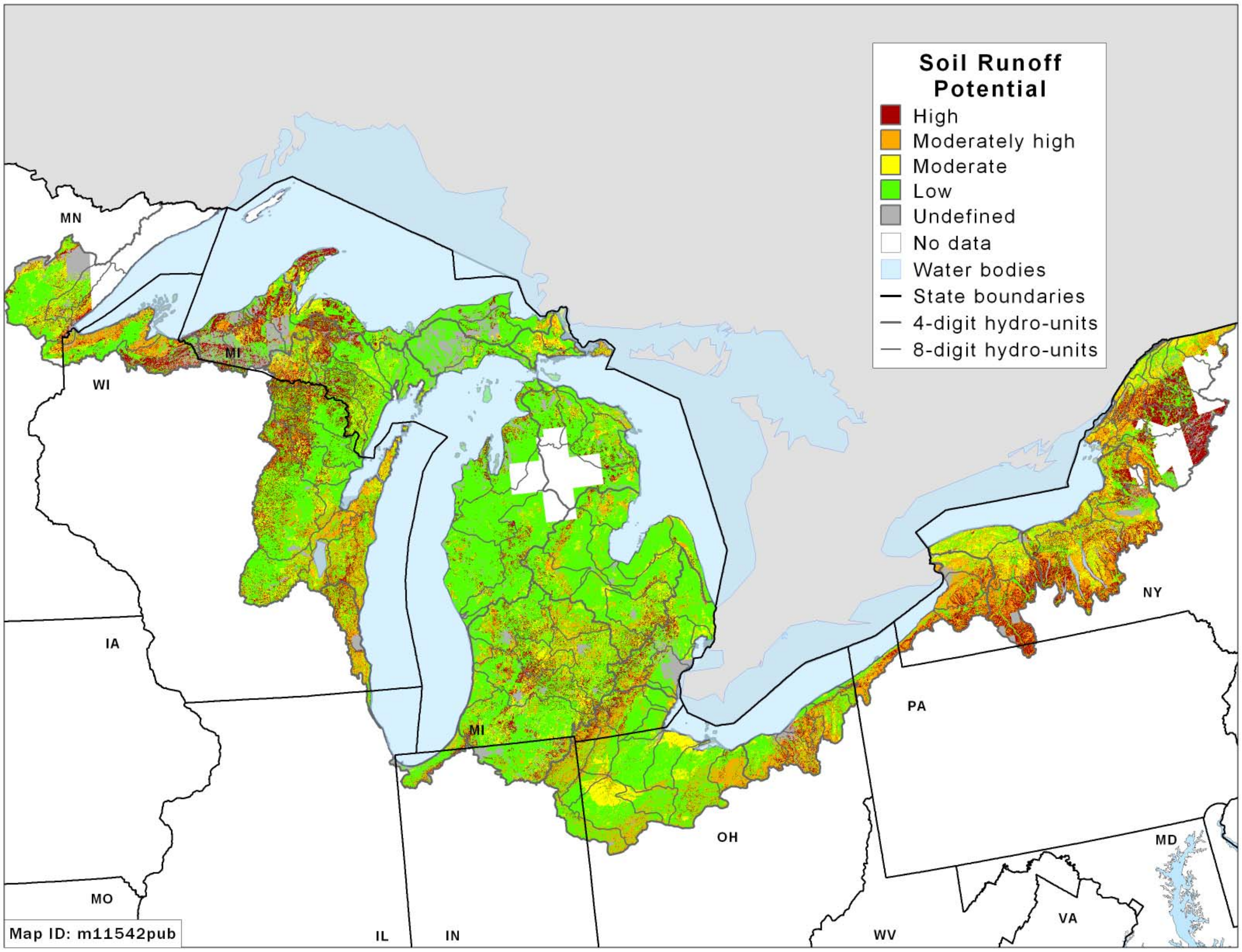
- **Group A—**sand, loamy sand, or sandy loam soils that have low runoff potential and high infiltration rates even when thoroughly wetted.
- **Group B**—silt loam or loam soils that have moderate infiltration rates when thoroughly wetted.
- **Group C**—sandy clay loam soils that have low infiltration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

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 17 percent of cropped acres in the Great Lakes Region is highly erodible land.

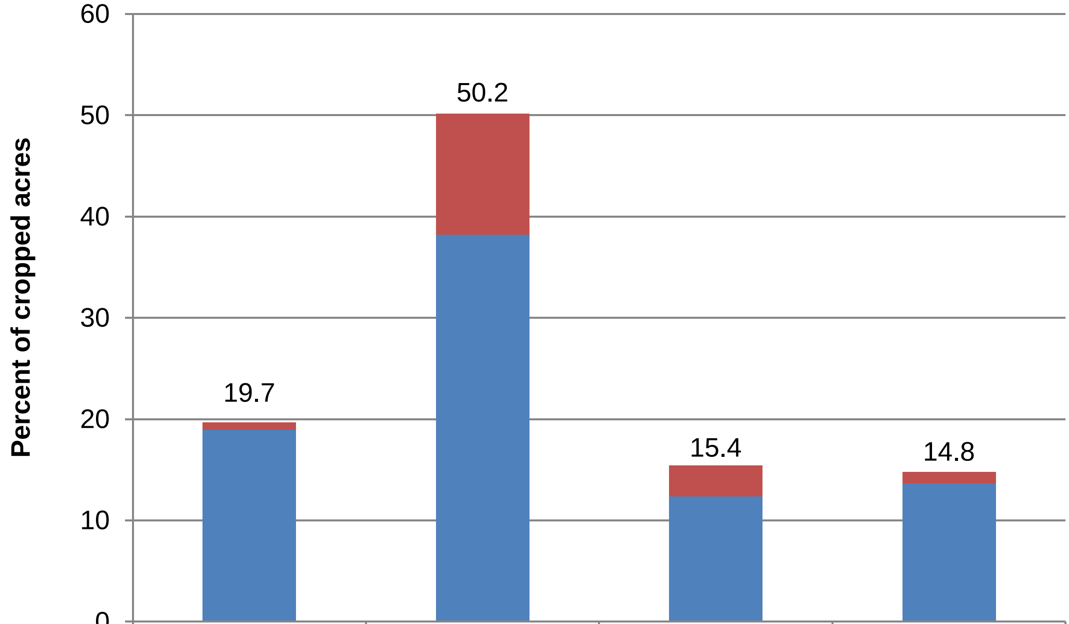
Note: See appendix B, table B3, for a breakdown of soil runoff potential by Lake basin.

Figure 54. Soil runoff potential for soils in the Great Lakes Region



Note: The soil runoff potential shown in this map was derived using the criteria presented in figure 53 applied to soil characteristics for SSURGO polygons. All soils and land uses are represented.

Figure 55. Soil leaching potential for cropped acres in the Great Lakes Region



	Low	Moderate	Moderately high	High
HEL	0.7	12.0	3.0	1.1
Non-HEL	19.0	38.2	12.4	13.7

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

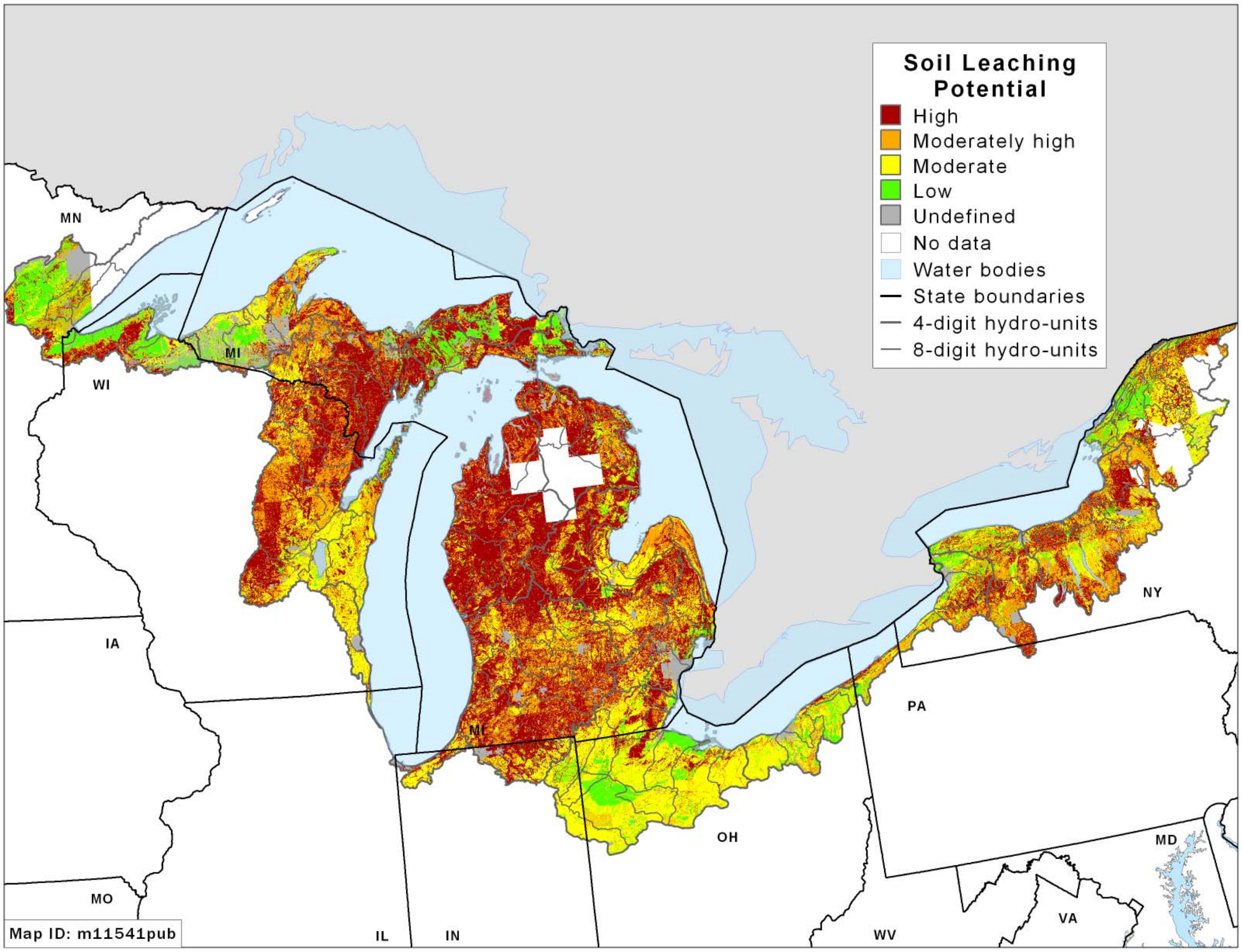
Coarse fragments (stones and rocks) in the soil make it easier for water to infiltrate rather than run off. If the coarse fragment content of the soil was greater than 30 percent, the soil leaching potential was increased two levels (moderate and moderately high to high, and low to moderately high).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

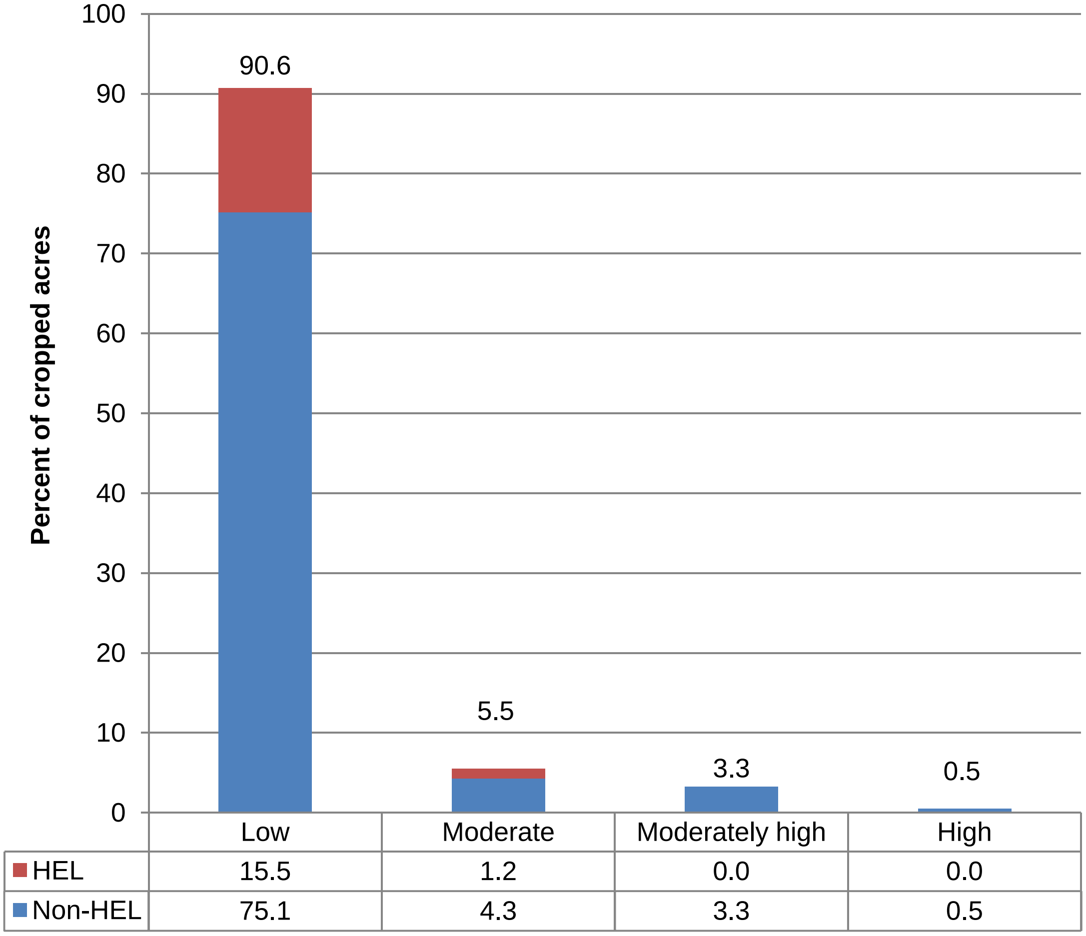
Note: K-factor is a relative index of susceptibility of bare, cultivated soil to particle detachment and transport by rainfall. It is determined by the composition of the soil, saturated hydraulic conductivity, and soil structure.
Note: About 17 percent of cropped acres in the Great Lakes Region is highly erodible land.
Note: See appendix B, table B3, for a breakdown of soil leaching potential by Lake basin.

Figure 56. Soil leaching potential for soils in the Great Lakes Region



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

Figure 57. Soil wind erosion potential for cropped acres in the Great Lakes Region



Criteria for four classes of wind erosion potential were derived using a combination of annual precipitation, percent slope, and the I-factor from the wind erosion equation*, as shown in the table below:

Soil wind erosion potential	Acres with I-factor <56	Acres with I-factor <134 and >=56	Acres with I-factor <250 and >=134	Acres with I-factor >=250
Low	Precipitation>=635 mm	Precipitation>=767 mm	Precipitation>=767 mm	None
Moderate	Precipitation<635 mm but >380mm	Precipitation<767 mm but >=508mm and slope>0.5	Precipitation <767 mm but >=635 mm or Precipitation <635 mm but >=508 mm and slope>=3	None
Moderately high	Precipitation<=380 mm	Precipitation<767 mm but >=508 mm and slope<=0.5 or Precipitation <508 mm	Precipitation <635 mm but >=508 mm and slope<3	None
High	None	None	Precipitation<508mm	All acres

* The I-factor from the wind erosion equation is a soil-erodibility index related to cloddiness.

Note: About 17 percent of cropped acres in the Great Lakes Region is highly erodible land.

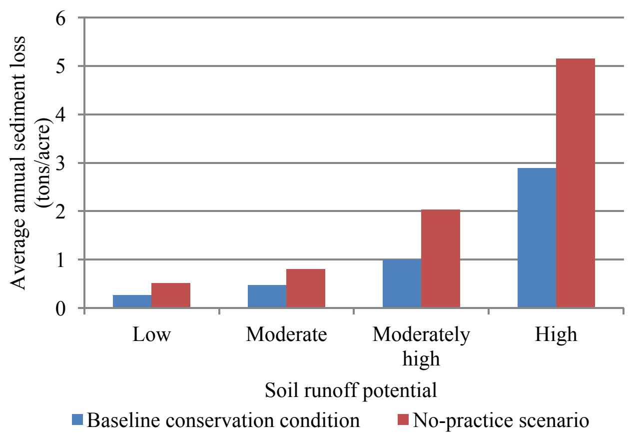
Note: See appendix B, table B3, for a breakdown of soil wind erosion potential by Lake basin.

Estimates of wind erosion, sediment loss, and nutrient losses for the no-practice scenario (without conservation practices) demonstrate how vulnerability factors influence losses in the Great Lakes Region.

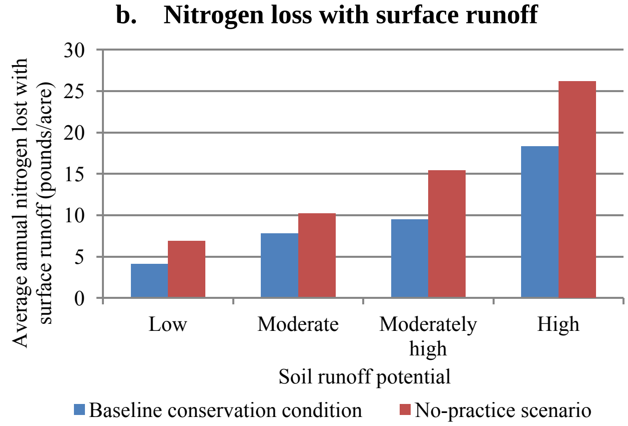
- Sediment loss for acres with a low soil runoff potential would have averaged 0.52 ton per acre per year without conservation practices, compared to 5.2 tons per acre per year for acres with a high soil runoff potential (fig. 58a).
- Nitrogen loss with surface runoff for acres with a low soil runoff potential would have averaged 7 pounds per acre per year, compared to 26 pounds per acre per year for acres with a high soil runoff potential (fig. 58b).
- Nitrogen loss in subsurface flows for acres with a low soil leaching potential would have averaged 23 pounds per acre per year, compared to 55 pounds per acre per year for acres with a high soil leaching potential (fig. 58c).
- Phosphorus lost to surface water for acres with a low soil runoff potential would have averaged 2.4 pounds per acre per year, compared to 6.4 pounds per acre per year for acres with a high soil runoff potential (fig. 58d).
- Wind erosion for acres with a low wind erosion potential would have averaged 1.3 tons per acre per year, compared to 6.8 tons per acre per year for acres with a high wind erosion potential (fig. 58e).

Figure 58. Average annual wind erosion, sediment loss, and nutrient losses for four levels of vulnerability potentials, Great Lakes Region.

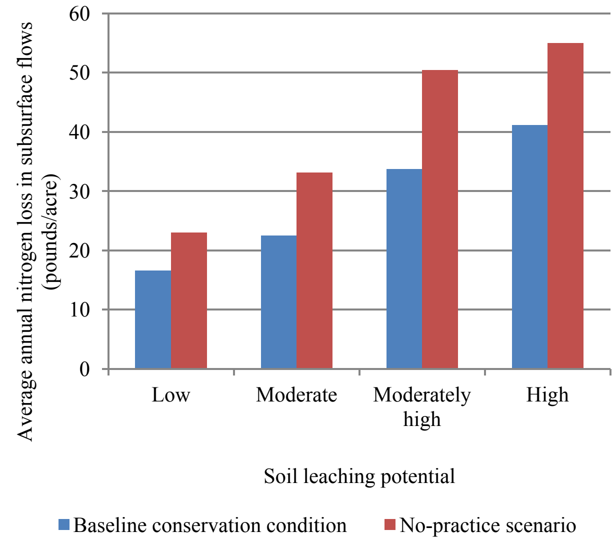
a. Sediment loss



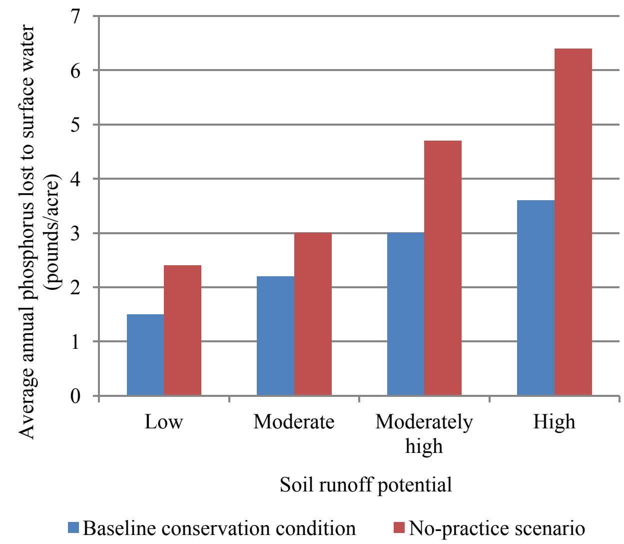
b. Nitrogen loss with surface runoff



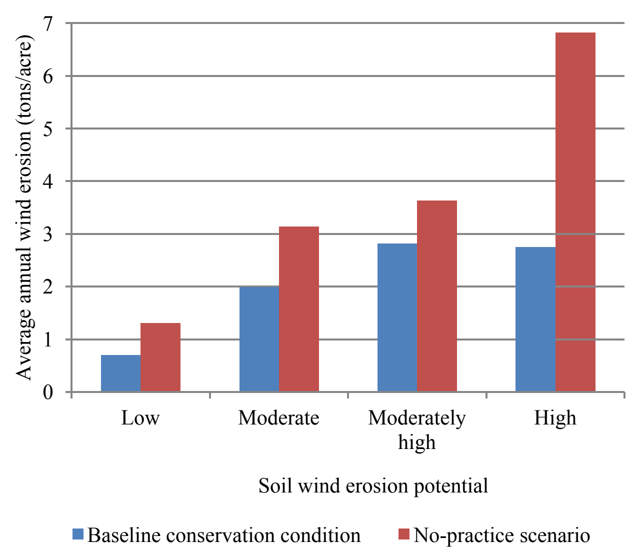
c. Nitrogen loss in subsurface flows



d. Phosphorus lost to surface water



e. Wind erosion



Evaluation of Conservation Treatment

The "matrix approach"

A "matrix approach" is used to identify acres where the level of conservation treatment in the baseline was inadequate relative to the level of inherent vulnerability due to soils and climate. These acres are referred to as "under-treated acres." Cropped acres were divided into 16 groups—combinations of four soil vulnerability potentials and four conservation treatment levels. The high or moderately high treatment levels are effective in reducing losses for all soil potentials, as shown in figures 59 through 63.

The matrixes are presented in tables 23 through 27. Acres and model results for each of the 16 groupings are presented in the first five matrixes in each table. This matrix approach was very effective in segregating acres with high losses from acres with low losses.

- Estimates of sediment and nutrient loss for the no-practice scenario consistently increased from small losses for the low soil runoff or leaching potential to large losses for the high soil runoff or leaching potential. As the no-practice scenario represents crop production without conservation practices, there is no consistent relationship in loss estimates among the four conservation treatment levels. The differences in losses among conservation treatment levels reflect the underlying variability, which is also influenced by the number of acres in each group.
- Estimates of sediment and nutrient loss for the baseline conservation condition exhibit a nearly consistent trend of decreasing loss with increasing treatment level within each soil runoff or leaching potential.
- The highest losses in the baseline conservation condition were for groups of acres where the conservation treatment level was one step or more below the soil leaching or runoff potential.

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

- Acres with a "high" level of need for conservation treatment consist of the most critical under-treated acres in the region. These are the most vulnerable of the under-treated acres with the least conservation treatment and have the highest losses of sediment and/or nutrients.
- Acres with a "moderate" level of need for conservation treatment consist of under-treated acres that generally have lower levels of vulnerability and/or have more conservation practice use than acres with a high level of need. The treatment level required is not necessarily less, although it can be, but rather the sediment and nutrient losses are lower and thus there is less potential on a per-acre basis for reducing agricultural pollutant loadings with additional conservation treatment.

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

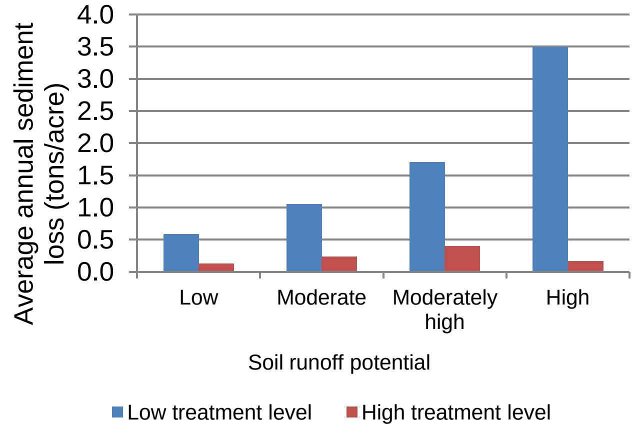
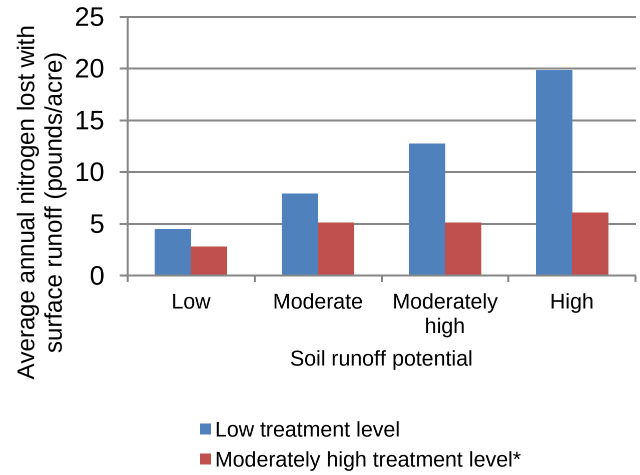
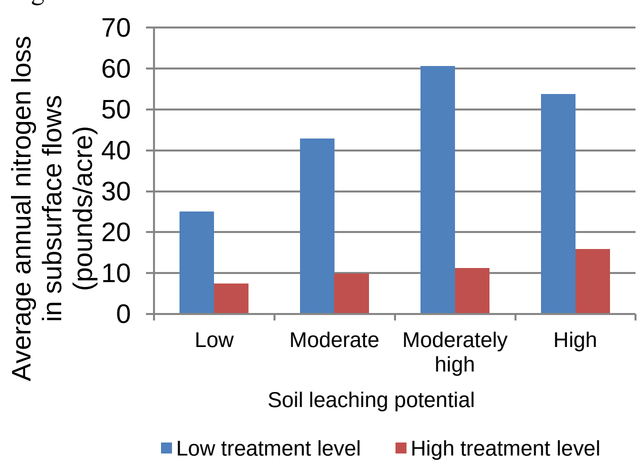


Figure 60. Trend in average annual nitrogen loss with surface runoff for increasing levels of soil runoff potential at two levels of conservation treatment, Great Lakes Region.



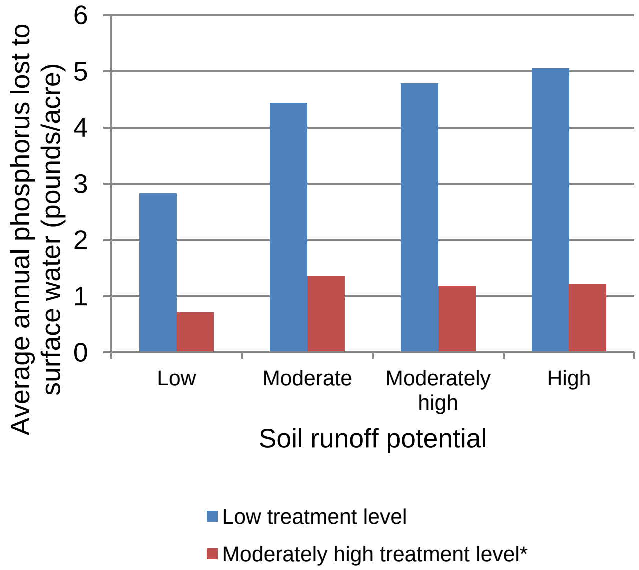
* There was not sufficient sample size to report values for the high treatment class.

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



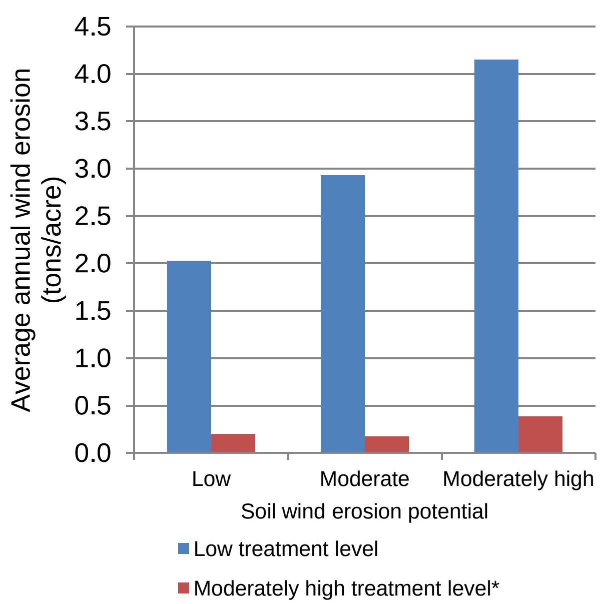
- Acres with a "low" level of need for conservation treatment consist of acres that are adequately treated with respect to the level of inherent vulnerability. While gains can be obtained by adding conservation practices to some of these acres, additional conservation treatment would reduce field losses by only a small amount.

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



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

Figure 63. Trend in average annual wind erosion for increasing levels of soil wind erosion potential at two levels of conservation treatment, Great Lakes Region



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

The last two matrixes in each of the tables 23 through 27 shows how conservation treatment needs were identified. Specific criteria were used to identify the groups of acres that fall into each of the three levels of conservation treatment need. Criteria were <u>not</u> tailored to a specific region, but were derived for use in all regions of the country to allow for comparisons of under-treated acres across regions using a consistent analytical framework. The criteria and steps in the process are as follows.

1. The percentage of acres that exceeded a given level of loss was estimated for each cell in the matrix as a guide to determining the extent of excessive losses, shown in tables 23 through 27. These are referred to as "acceptable levels." *Losses above these levels were treated as unacceptable levels of loss.* "Acceptable levels" for field-level losses used for this purpose are[20]—
   - Long-term average of 2 tons per acre per year sediment loss
   - Long-term average of 15 pounds per acre per year nitrogen loss with surface runoff (soluble and sediment attached)
   - Long-term average of 25 pounds per acre per year nitrogen loss in subsurface flows
   - Long-term average of 4 pounds per acre per year phosphorus lost to surface water (soluble and sediment attached)
   - Long-term average of 4 tons per acre per year wind erosion
2. Groups of acres with less than 30 percent of the acres exceeding acceptable levels were defined as adequately treated acres and designated as having a **low level of conservation treatment need**.
3. Groups of acres with more than 60 percent of the acres in excess of acceptable levels were designated as having a **high level of conservation treatment need,** indicated by darker shaded cells in the matrixes.
4. The remaining acres were designated as having a **moderate level of conservation treatment need**, indicated by lighter shaded cells in the matrix.

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

[20] 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 Great Lakes Region, for example, percentages of acres that can attain these acceptable levels with additional soil erosion control and nutrient management practices on all under-treated acres are (see the next chapter)—

- 98 percent of cropped acres for sediment loss,
- 98 percent of cropped acres for nitrogen loss with surface runoff,
- 89 percent of cropped acres for nitrogen loss in subsurface flows,
- 95 percent of cropped acres for phosphorus lost to surface water, and
- 98 percent of cropped acres for wind erosion.

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 under-treated acres; and thus, all acres below that level of loss are considered adequately treated. A threshold approach is often used in regulatory schemes to denote compliance versus non-compliance.

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. In fact, 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 the acres with treatment needs can be readily identified by farmers and conservation planners and treated as needed. Soil vulnerability levels and the existing conservation treatment levels can be readily determined during the conservation planning process.

Table 23. Identification of under-treated acres for sediment loss due to water erosion in the Great Lakes Region

	Conservation treatment levels for water erosion control				
Soil runoff potential	Low	Moderate	Moderately high	High	All
Estimated cropped acres					
Low	1,269,504	3,554,887	576,900	2,408,956	7,810,247
Moderate	577,684	709,676	249,490	1,318,449	2,855,299
Moderately high	959,361	1,392,205	345,974	498,434	3,195,974
High	567,522	315,012	51,213	8,233	941,980
All	3,374,071	5,971,780	1,223,577	4,234,072	14,803,500
Percent of cropped acres					
Low	9	24	4	16	53
Moderate	4	5	2	9	19
Moderately high	6	9	2	3	22
High	4	2	<1	<1	6
All	23	40	8	29	100
Sediment loss estimates *without* conservation practices (no-practice scenario, average annual tons/acre)					
Low	0.74	0.53	0.62	0.37	0.52
Moderate	1.58	0.74	0.62	0.54	0.81
Moderately high	2.77	1.81	1.92	1.28	2.03
High	5.16	5.00	6.39	3.11	5.15
All	2.20	1.09	1.23	0.54	1.20
Sediment loss estimates for the baseline conservation condition (average annual tons/acre)					
Low	0.58	0.28	0.15	0.13	0.27
Moderate	1.06	0.47	0.32	0.23	0.47
Moderately high	1.71	0.89	0.35	0.40	1.00
High	3.49	2.28	0.37	0.16	2.89
All	1.47	0.55	0.25	0.19	0.63
Percent reduction in sediment loss due to conservation practices					
Low	21	47	77	65	48
Moderate	33	36	49	57	42
Moderately high	38	51	82	69	51
High	32	54	94	95	44
All	33	49	80	64	47
Percent of acres in baseline conservation condition with average annual sediment loss more than 2 tons/acre					
Low	4	1	0	0	1
Moderate	12	3	0	0	3
Moderately high	27	10	0	0	13
High	64	44	0	0	53
All	22	6	0	0	7
Estimate of under-treated acres					
Low	0	0	0	0	0
Moderate	0	0	0	0	0
Moderately high	0	0	0	0	0
High	567,522	315,012	0	0	882,534
All	567,522	315,012	0	0	882,534

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

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

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

Table 24. Identification of under-treated acres for nitrogen loss with surface runoff (sediment attached and soluble) in the Great Lakes Region

	Conservation treatment levels for nitrogen runoff control				
Soil runoff potential	Low	Moderate	Moderately high	High	All
Estimated cropped acres					
Low	965,974	3,804,601	2,538,953	500,719	7,810,247
Moderate	389,507	978,937	1,351,921	134,935	2,855,299
Moderately high	569,068	1,813,395	782,890	30,621	3,195,974
High	307,863	593,993	40,123	0	941,980
All	2,232,412	7,190,926	4,713,887	666,275	14,803,500
Percent of cropped acres					
Low	7	26	17	3	53
Moderate	3	7	9	1	19
Moderately high	4	12	5	<1	22
High	2	4	<1	0	6
All	15	49	32	5	100
Estimates of nitrogen loss with surface runoff *without* conservation practices (no-practice scenario, average annual pounds/acre)					
Low	8.5	7.4	6.1	4.7	6.9
Moderate	11.6	11.4	9.3	6.9	10.2
Moderately high	19.7	16.4	10.0	7.1	15.4
High	24.1	27.7	20.2	NA	26.2
All	14.0	11.9	7.8	5.3	10.6
Estimates of nitrogen loss with surface runoff for the baseline conservation condition (average annual pounds/acre)					
Low	4.5	3.7	2.8	1.9	4.1
Moderate	8.0	6.6	5.1	3.9	7.8
Moderately high	12.8	10.1	5.1	5.6	9.5
High	19.9	17.1	6.1	NA	18.3
All	9.3	6.8	3.9	2.5	8.8
Percent reduction in nitrogen loss with surface runoff due to conservation practices					
Low	47	50	53	60	51
Moderate	31	42	45	44	42
Moderately high	35	39	49	20	39
High	17	38	70	NA	33
All	33	43	50	53	43
Percent of acres in baseline conservation condition with average annual nitrogen loss with surface runoff more than 15 pounds/acre					
Low	5	1	0	0	1
Moderate	11	4	2	0	4
Moderately high	29	16	1	0	14
High	57	47	11	NA	49
All	19	9	1	0	8
Estimate of under-treated acres for nitrogen loss with surface runoff					
Low	0	0	0	0	0
Moderate	0	0	0	0	0
Moderately high	0	0	0	0	0
High	307,863	593,993	0	0	901,857
All	307,863	593,993	0	0	901,857

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

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

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

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

Table 25. Identification of under-treated acres for nitrogen loss in subsurface flows in the Great Lakes Region

Soil leaching potential	Conservation treatment levels for nitrogen management: Low	Moderate	Moderately high	High	All
Estimated cropped acres					
Low	264,396	1,467,156	795,607	385,196	2,912,354
Moderate	665,980	3,400,910	1,958,592	1,398,482	7,423,964
Moderately high	231,499	1,045,379	627,857	373,585	2,278,319
High	238,338	869,681	626,154	454,690	2,188,863
All	1,400,213	6,783,126	4,008,209	2,611,952	14,803,500
Percent of cropped acres					
Low	2	10	5	3	20
Moderate	5	23	13	9	50
Moderately high	2	7	4	3	15
High	2	6	4	3	15
All	9	46	27	18	100
Estimates of nitrogen loss in subsurface flows *without* conservation practices (no-practice scenario, average annual pounds/acre)					
Low	32.1	22.9	22.6	17.8	23.0
Moderate	55.6	34.6	28.9	24.3	33.1
Moderately high	77.8	57.3	38.6	34.2	50.4
High	69.4	64.7	57.6	25.1	55.0
All	57.2	39.4	33.7	24.9	37.0
Estimates of nitrogen loss in subsurface flows for the baseline conservation condition (average annual pounds/acre)					
Low	25.0	21.6	9.3	7.4	16.6
Moderate	42.8	29.6	12.2	9.9	22.5
Moderately high	60.6	47.2	14.7	11.2	33.7
High	53.8	56.7	32.9	15.8	41.1
All	44.3	34.0	15.2	10.8	25.8
Percent reduction in nitrogen loss in subsurface flows due to conservation practices					
Low	22	6	59	59	28
Moderate	23	15	58	59	32
Moderately high	22	18	62	67	33
High	23	12	43	37	25
All	23	14	55	57	30
Percent of acres in baseline conservation condition with average annual nitrogen loss in subsurface flows more than 25 pounds/acre					
Low	33	24	3	2	16
Moderate	50	41	5	3	25
Moderately high	59*	65	10	1	39
High	79	70	22	4	44
All	53	45	8	3	28
Estimate of under-treated acres for nitrogen loss in subsurface flows					
Low	264,396	0	0	0	264,396
Moderate	665,980	3,400,910	0	0	4,066,890
Moderately high	231,499	1,045,379	0	0	1,276,878
High	238,338	869,681	0	0	1,108,019
All	1,400,213	5,315,970	0	0	6,716,183

Note: Cells below the red boundary shown for the baseline conservation condition are the acres where the level of conservation treatment is one step or more below the soil leaching potential. These cells consistently had the highest losses in the model simulations.
Note: Color-shaded cells indicate under-treated acres; groups of acres with more than 30 percent of the acres exceeding acceptable levels were defined as under-treated acres. Darker color-shaded cells indicate critical under-treated acres; critical under-treated acres were defined as groups of acres with more than 60 percent of the acres in excess of acceptable levels.
Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Percents may not add to totals because of rounding.
* This group of acres was classified as critical under-treated acres because a higher level of conservation treatment met the criteria for critical under-treated acres.

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

Soil runoff potential	Conservation treatment levels for phosphorus runoff control: Low	Moderate	Moderately high	High	All
Estimated cropped acres					
Low	1,640,073	2,926,015	2,529,453	714,705	7,810,247
Moderate	543,137	1,186,329	847,588	278,247	2,855,299
Moderately high	788,911	1,701,037	627,685	78,341	3,195,974
High	407,821	483,075	51,083	0	941,980
All	3,379,942	6,296,456	4,055,809	1,071,293	14,803,500
Percent of cropped acres					
Low	11	20	17	5	53
Moderate	4	8	6	2	19
Moderately high	5	11	4	1	22
High	3	3	<1	0	6
All	23	43	27	7	100
Phosphorus lost to surface water *without* conservation practices (no-practice scenario, average annual pounds/acre)					
Low	3.2	2.4	1.9	1.9	2.4
Moderate	4.5	2.3	2.9	2.7	3.0
Moderately high	5.9	4.9	3.1	3.4	4.7
High	6.2	6.7	5.3	NA	6.4
All	4.4	3.4	2.4	2.2	3.3
Phosphorus lost to surface water for the baseline conservation condition (average annual pounds/acre)					
Low	2.8	1.7	0.7	0.5	1.5
Moderate	4.4	2.1	1.4	0.8	2.2
Moderately high	4.8	2.8	1.2	0.9	3.0
High	5.1	2.7	1.2	NA	3.6
All	3.8	2.2	0.9	0.6	2.1
Percent reduction in phosphorus lost to surface water due to conservation practices					
Low	11	28	63	73	36
Moderate	2	11	53	71	26
Moderately high	18	41	61	74	37
High	18	61	77	NA	43
All	13	36	61	72	36
Percent of acres in baseline conservation condition with average annual phosphorus lost to surface water more than 4 pounds/acre					
Low	16	9	1	0	7
Moderate	37	11	7	0	14
Moderately high	44	18	4	0	21
High	50	10	0	NA	27
All	30	12	3	0	13
Estimate of under-treated acres for phosphorus lost to surface water					
Low	0	0	0	0	0
Moderate	543,137	0	0	0	543,137
Moderately high	788,911	0	0	0	788,911
High	407,821	0	0	0	407,821
All	1,739,869	0	0	0	1,739,869

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

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

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

Table 27. Identification of under-treated acres for wind erosion in the Great Lakes Region

Soil wind erosion potential	Conservation treatment levels for wind erosion control: Low	Moderate	Moderately high	High	All
Estimated cropped acres					
Low	1,938,227	6,440,460	4,691,594	353,742	13,424,022
Moderate	355,313	377,474	76,897	8,237	817,920
Moderately high	219,413	238,701	23,604	0	481,717
High	8,321	25,302	24,461	21,756	79,841
All	2,521,273	7,081,937	4,816,555	383,734	14,803,500
Percent of cropped acres					
Low	13	44	32	2	91
Moderate	2	3	1	<1	6
Moderately high	1	2	<1	0	3
High	<1	<1	<1	<1	1
All	17	48	33	3	100
Wind erosion estimates *without* conservation practices (no-practice scenario, average annual tons/acre)					
Low	2.23	1.34	0.86	1.61	1.31
Moderate	3.51	3.23	0.83	*	3.14
Moderately high	4.45	3.04	2.01	NA	3.63
High	*	8.87	*	*	6.82
All	2.60	1.52	0.90	1.95	1.51
Wind erosion estimates for the baseline conservation condition (average annual tons/acre)					
Low	2.03	0.69	0.20	0.26	0.70
Moderate	2.93	1.49	0.18	*	1.99
Moderately high	4.15	1.83	0.39	NA	2.82
High	*	4.75	*	*	2.75
All	2.33	0.79	0.21	0.36	0.85
Percent reduction in wind erosion due to conservation practices					
Low	9	48	76	84	46
Moderate	17	54	79	*	37
Moderately high	7	40	81	NA	22
High	*	46	*	*	60
All	10	48	76	81	44
Percent of acres in baseline conservation condition with average annual wind erosion more than 4 tons/acre					
Low	13	3	0	0	4
Moderate	27	9	0	*	16
Moderately high	42	12	0	NA	25
High	*	40	*	*	21
All	18	4	0	2	5
Estimate of under-treated acres					
Low	0	0	0	0	0
Moderate	0	0	0	0	0
Moderately high	219,413	0	0	0	219,413
High	8,321	25,302	0	0	33,623
All	227,733	25,302	0	0	253,036

Note: Cells below the red boundary shown for the baseline conservation condition are the acres where the level of conservation treatment is one step or more below the soil runoff potential. These cells consistently had the highest losses in the model simulations.
Note: Color-shaded cells indicate under-treated acres; groups of acres with more than 30 percent of the acres exceeding acceptable levels were defined as under-treated acres. Darker color-shaded cells indicate critical under-treated acres; critical under-treated acres were defined as groups of acres with more than 60 percent of the acres in excess of acceptable levels.
Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Percents may not add to totals because of rounding.
* Estimate not reported because there were too few sample points available in the category.

Conservation treatment needs by resource concern

The proportion of cropped acres with a high or moderate need for additional conservation treatment was determined to be (fig. 64)—

- 6 percent for sediment loss (4 percent with a high need for treatment),
- 6 percent for nitrogen loss with runoff (no acres with a high need for treatment),
- 12 percent for phosphorus lost to surface water (no acres with a high need for treatment),
- 45 percent for nitrogen loss in subsurface flows (16 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, and
- 2 percent for wind erosion (no acres with a high need for treatment).

Under-treated acres in the Great Lakes Region are presented by combinations of resource concerns in table 28. About 78 percent of under-treated acres are under-treated for only one of the five resource concerns, usually nitrogen leaching:

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

Nitrogen leaching and phosphorus runoff was the most frequently occurring combination of resource concerns, representing 9 percent of under-treated acres (table 28). About 3 percent of under-treated acres need treatment for all resource concerns except wind erosion.

The most critical conservation concern in the region is the need for complete and consistent use of nutrient management—appropriate rate, form, timing, *and* method of application. While most cropped acres have some nutrient management practices in use, 52 percent have a high or moderate need for additional nutrient management for nitrogen or phosphorus (table 28). About 16 percent have a high need for additional nutrient management.

Figure 64. Percent of cropped acres that are under-treated in the Great Lakes Region, by resource concern

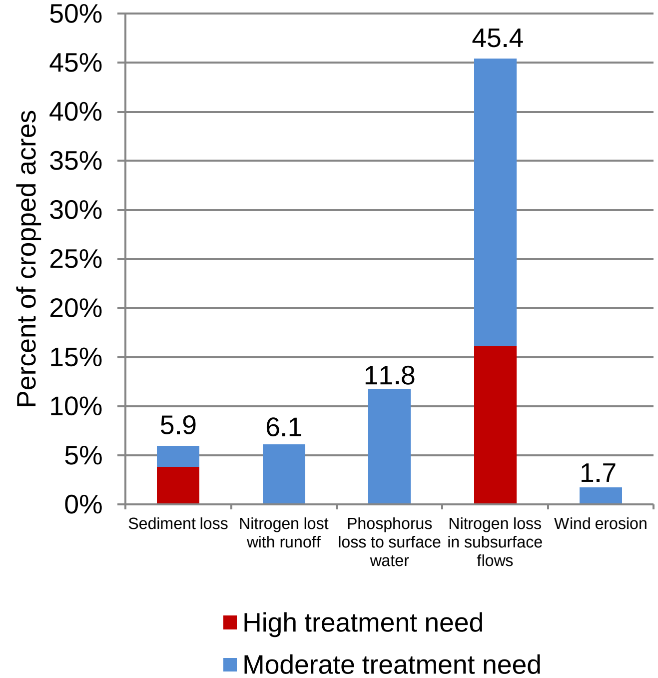


Table 28. Under-treated acres with resource concerns needing treatment in the Great Lakes Region

Reason for treatment need	Estimated acres needing treatment	Percent of cropped acres	Percent of under-treated acres
Nitrogen leaching only	5,384,752	36.4	68.3
Nitrogen leaching and phosphorus runoff	684,252	4.6	8.7
Phosphorus runoff only	647,796	4.4	8.2
Sediment loss and nitrogen runoff	267,258	1.8	3.4
Sediment loss, nitrogen and phosphorus runoff, and nitrogen leaching	250,165	1.7	3.2
Sediment loss, nitrogen runoff, and nitrogen leaching	200,111	1.4	2.5
Wind and nitrogen leaching	170,237	1.1	2.2
Sediment loss, nitrogen runoff and phosphorus runoff	157,656	1.1	2.0
Wind only	82,799	0.6	1.1
Nitrogen leaching and nitrogen runoff	26,666	0.2	0.3
Sediment loss only	7,344	<0.1	0.1
All under-treated acres	7,879,035	53.2	100.0

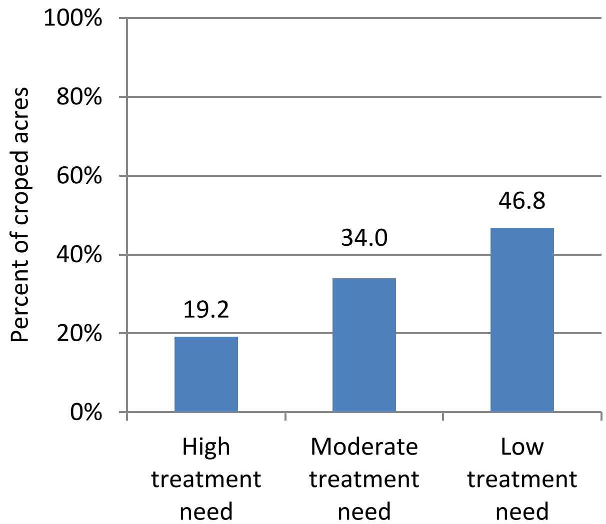
Note: This table summarizes the under-treated acres identified in tables 23-27 and reports the joint set of acres that need treatment according to combinations of resource concerns.
Note: Percents may not add to totals because of rounding.

Conservation treatment needs for one or more resource concern

Some acres require additional treatment for only one of the five resource concerns, while other acres require additional treatment for two or more resource concerns. After accounting for acres that need treatment for multiple resource concerns, the evaluation of treatment needs for the Great Lakes Region determined the following (fig. 65):

- 19 percent of cropped acres (2.8 million acres) have a **high** level of need for additional conservation treatment.
- 34 percent of cropped acres (5.0 million acres) have a **moderate** level of need for additional conservation treatment.
- 47 percent of cropped acres (6.9 million acres) have a **low** level of need for additional treatment and are considered to be adequately treated.

Figure 65. 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 Great Lakes Region



High level of need for conservation treatment. Acres with a "high" level of need for conservation treatment consist of the most critical under-treated acres in the region (table 29 and figs. 66 and 67). These are the most vulnerable of the under-treated acres with the least conservation treatment and have the highest losses of sediment and/or nutrients. Seventy-four percent of these acres have losses higher than the acceptable level criteria used in the matrix approach for at least one of the five resource concerns. These acres lose (per acre per year, on average)—

- 1.1 tons of sediment by water erosion,
- 2.7 pounds of phosphorus,
- 7 pounds of nitrogen with surface runoff,
- 49 pounds of nitrogen in subsurface flows, and
- 1.6 tons of soil by wind erosion.

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

Moderate level of need for conservation treatment. Acres with a "moderate" level of need for conservation treatment consist of under-treated acres that generally have lower levels of vulnerability and/or have more conservation practice use than acres with a high level of need (table 29 and figs. 66 and 67). The sediment and nutrient losses are lower than those with a high need for additional treatment and thus there is less potential on a per-acre basis for reducing agricultural pollutant loadings with additional conservation treatment. Fifty-four percent of these acres have losses higher than the acceptable level criteria used in the matrix approach for at least one of the five resource concerns. These acres lose (per acre per year, on average)—

- 0.7 ton of sediment by water erosion,
- 2.6 pounds of phosphorus,
- 7 pounds of nitrogen with surface runoff,
- 28 pounds of nitrogen in subsurface flows, and
- 0.7 ton of soil by wind erosion.

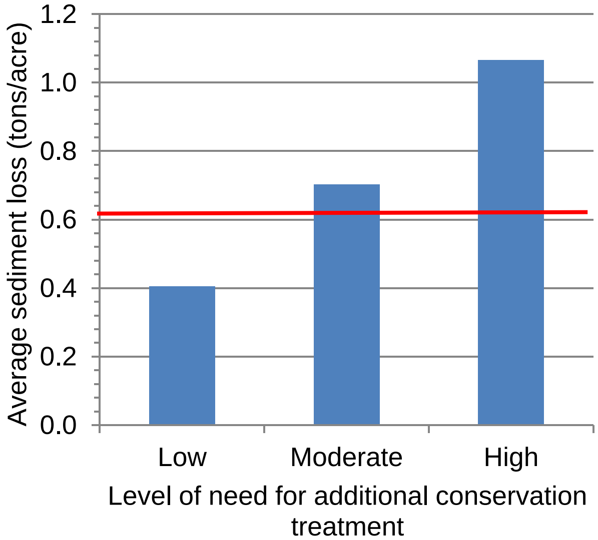
While the benefit of additional treatment of acres with a moderate level of treatment need is less than for acres with a high level of treatment need, a portion of these acres may need to be treated to meet water quality goals in the region.

Low level of need for conservation treatment. Acres with a low level of need for conservation treatment consist of acres that are adequately treated with respect to the level of inherent vulnerability (table 29 and figs. 66 and 67). These acres lose (per acre per year, on average)—

- 0.4 ton of sediment by water erosion,
- 1.5 pounds of phosphorus,
- 5 pounds of nitrogen with surface runoff,
- 15 pounds of nitrogen in subsurface flows, and
- 0.6 ton of soil by wind erosion

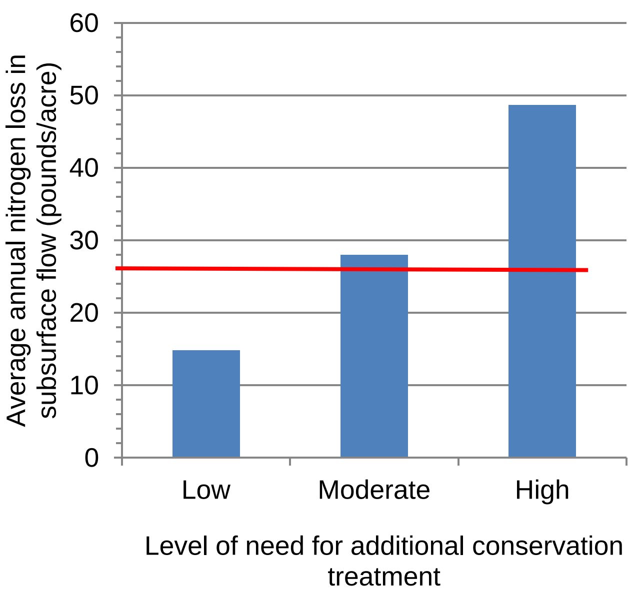
While gains can be obtained by adding conservation practices to some of these acres, additional conservation treatment would reduce field losses by only a small amount.

Figure 66. Average per-acre sediment loss for three levels of conservation treatment need for one or more resource concerns, Great Lakes Region



Note: The average sediment loss for all cropped acres is 0.63 tons per acre per year, shown in red.

Figure 67. Average per-acre nitrogen loss in subsurface flow pathways for three levels of conservation treatment need for one or more resource concerns, Great Lakes Region



Note: The average nitrogen loss in subsurface flow pathways for all cropped acres is 25.8 pounds per acre per year, shown in red.

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 29. Baseline conservation condition model simulation results for subsets of under-treated and adequately treated acres in the Great Lakes Region

Model simulated outcome	Acres with a *low* need for treatment	Acres with a *moderate* need for treatment	Acres with a *high* need for treatment	All acres
Cultivated cropland acres in subset	6,924,465	5,036,722	2,842,314	14,803,500
Percent of acres	46.8%	34.0%	19.2%	100%
Water flow				
Average annual surface runoff (inches)	4.5	4.6	4.1	4.5
Average annual subsurface water flow (inches)	7.6	7.7	9.3	7.9
Erosion and sediment loss				
Average annual wind erosion (tons/acre)	0.6	0.7	1.6	0.9
Average annual sheet and rill erosion (tons/acre)	0.3	0.5	0.6	0.4
Average annual sediment loss at edge of field due to water erosion (tons/acre)	0.4	0.7	1.1	0.6
Soil organic carbon				
Average annual change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)	-46	-21	-155	-58
Nitrogen				
Nitrogen applied (pounds/acre)	56	91	105	78
Nitrogen in crop yield removed at harvest (pounds/acre)	98	95	90	96
Total nitrogen loss for all pathways (pounds/acre)	32	51	74	47
Average annual loss of nitrogen through volatilization (pounds/acre)	6	8	7	7
Average annual nitrogen returned to the atmosphere through denitrification (pounds/acre)	2	3	3	2
Average annual loss of nitrogen with surface runoff, including waterborne sediment (pounds/acre)	5	7	7	6
Average annual nitrogen loss in subsurface flows (pounds/acre)	15	28	49	26
Phosphorus l				
Phosphorus applied (pounds/acre)	17.7	22.9	24.3	20.7
Total phosphorus loss for all pathways (pounds/acre)	2.3	3.6	4.9	3.2
Loss of phosphorus to surface water, including both soluble and sediment attached (pounds/acre)*	1.5	2.6	2.7	2.1
Pesticide loss				
Average annual mass loss of pesticides for all pathways (grams of active ingredient/hectare)	9.3	10.2	15.9	10.9
Average annual surface water pesticide risk indicator for aquatic ecosystem	1.8	2.0	2.0	1.9
Average annual surface water pesticide risk indicator for humans	0.4	0.4	0.6	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

The breakdown of under-treated acres by cropping system showed a generally proportionate distribution of under-treated acres among cropping systems, shown in table 30. Percentages of under-treated acres are close to the same percentages of the region's cultivated cropland in each basin. For the critical under-treated acres (acres with a high need for treatment), the disproportionately higher percentage is fairly large for rotations that include vegetables, indicating that this cropping system tends to occur more frequently on the more vulnerable acres within the region or had less conservation treatment. Cropping systems that included soybean tended to have disproportionately fewer acres needing additional conservation treatment.

Table 30. Under-treated acres by cropping system in the Great Lakes Region

		Critical under-treated acres (acres with a *high* level of treatment need)			All under-treated acres (acres with a *high* or *moderate* level of treatment need)		
Cropping system	Percent of cropped acres in Great Lakes Region	Acres	Percent of acres in Great Lakes Region	Percent of acres in cropping system	Acres	Percent of acres in Great Lakes Region	Percent of acres in cropping system
Corn-soybean only	40	986,387	35	17	3,105,466	39	53
Corn-soybean with close grown crops	13	291,285	10	15	1,154,604	15	61
Corn only	11	428,489	15	28	932,078	12	60
Corn and close grown crops	3	130,594	5	27	322,679	4	67
Soybean-wheat only	7	77,308	3	7	327,180	4	31
Soybean only	5	33,409	1	5	100,348	1	14
Hay-crop mix	11	334,874	12	21	855,882	11	53
Vegetable or tobacco with or without other crops	7	448,828	16	41	814,698	10	75
Remaining mix of crops	3	111,140	4	23	266,100	3	54
Total	100	2,842,314	100	19	7,879,035	100	53

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

Conservation treatment needs by Lake basins

Under-treated acres in the Great Lakes Region are presented in table 31 by basin. Percentages of under-treated acres are close to the same percentages of the region's cultivated cropland in each basin, indicating that under-treated acres are spread proportionately throughout the region (table 31). Critical under-treated acres, however, are disproportionately high in all basins except the Lake Erie basin. The Lake Erie basin has a disproportionately low share of critical under-treated acres; only 17 percent of the critical under-treated acres in the region are found in this basin, whereas the basin has 38 percent of the region's cropped acres. Only 8 percent of the cropped acres in the Lake Erie basin are critical under-treated acres.

Under-treated acres for sediment loss are proportionately highest in the Lake Ontario basin, where 11 percent of cropped acres have a high level of treatment need for sediment loss, compared to the regional average of 4 percent (appendix B, table B4). An additional 5 percent of the cropped acres in this region have a moderate need for additional treatment for sediment loss. The Lake Ontario basin also has the highest proportion of acres needing treatment for nitrogen lost with surface runoff (16 percent compared to the regional average of 6 percent) and for phosphorus loss (28 percent compared to the regional average of 12 percent). The Western Lake Michigan basin has relatively high proportions of conservation treatment needs for nitrogen lost with surface runoff (11 percent of cropped acres) and phosphorus loss (20 percent of cropped acres).

Critical under-treated acres for nitrogen loss in subsurface flows are lowest in the Lake Erie basin—only 6 percent of cropped acres compared to the regional average of 16 percent. However, this region has the highest percentage of cropped acres with a moderate need for additional treatment for nitrogen loss in subsurface flows—40 percent (appendix B, table B4).

Under-treated acres for wind erosion control are primarily in the Lake Huron basin, where 8 percent of cropped acres have a moderate need for additional treatment.

Table 31. Under-treated acres for basins in the Great Lakes Region

			Critical under-treated acres (acres with a *high* level of treatment need)			All under-treated acres (acres with a *high* or *moderate* level of treatment need)		
Basin name	Sub-region code	Percent of cropped acres in Great Lakes Region	Acres	Percent of acres in Great Lakes Region	Percent of acres in basin	Acres	Percent of acres in Great Lakes Region	Percent of acres in basin
Western Lake Michigan	0403, 0404	16	592,694	21	26	1,243,689	16	54
Eastern Lake Michigan	0405, 0406	23	873,752	31	25	1,855,182	24	54
Lake Huron	0407, 0408,	14	497,823	18	24	1,169,777	15	56
Lake Erie	0409, 0410, 0411, 0412	38	469,606	17	8	2,689,378	34	48
Lake Ontario	0413, 0414, 0415	9	408,439	14	32	913,710	12	71
	Regional Total	100	2,842,314	100	19	7,879,035	100	53

Notes: Percents may not add to totals because of rounding.
Note: Results for the Lake Superior basin are not shown as the CEAP sample for this basin was too small to provide estimates of conservation treatment needs.

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 Great Lakes Region. 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.

Two sets of 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), and
2. Application of nitrogen and phosphorus using appropriate rate, timing, and method.

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

1. Treatment of the 2.84 million critical under-treated acres (acres with a high need for conservation treatment) with wind and water erosion control practices only.
2. Treatment of all 7.9 million under-treated acres (acres with a high or moderate need for conservation treatment) with wind and water erosion control practices only.
3. Treatment of the 2.84 million critical under-treated acres with nutrient management practices in addition to erosion control practices to address nutrient losses.
4. Treatment of all 7.9 million under-treated acres with nutrient management practices in addition to erosion control practices to address nutrient losses.

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.

Long-term conserving cover was not included in the treatment scenarios. Long-term conserving cover represents the ultimate conservation treatment for acres that are highly vulnerable to sediment and nutrient loss, but if it was widely used, regional crop production levels could not be maintained. Enrolling more cultivated cropland acres in programs that provide the economic incentives for long-term conserving cover may be necessary in some areas to meet water quality goals for environmental protection.

Pesticide management was also not addressed 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.

Treatment scenarios were also not designed to represent actual program or policy options for the Great Lakes Region.

Economic and programmatic aspects—such as producer costs, conservation program costs, and capacity to deliver the required technical assistance—were not considered in the assessment of potential gains from further conservation treatment.

Simulation of Additional 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 32) 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.

For additional wind erosion control, the proportion of the field protected from wind was increased. Practices such as windbreaks or shelterbelts, cross wind ridges, stripcropping or trap strips, and hedgerows are typically used for wind control. The effectiveness of these practices is simulated in the model by adjusting the unsheltered dimensions of the standard field that is modeled—a square field 400 meters (1,312 feet) on each side. For sample points where the wind erosion exceeded an average of 4 tons per acre per year in the baseline conservation condition (760,000 acres), wind erosion practices were added so as to reduce the unsheltered distance to 120 feet. This was typically achieved by adding cross wind trap strips.

Table 32. Summary of additional structural practices for water erosion control simulated for under-treated acres to assess the potential for gains from additional conservation treatment in the Great Lakes Region

	Critical under-treated acres (acres with a high level of treatment need)		Non-critical under-treated acres (acres with a moderate level of treatment need)		All under-treated acres	
Additional practice	Treated acres	Percent of total	Treated acres	Percent of total	Treated acres	Percent of total
Overland flow practice only	26,627	1	45,619	1	72,245	1
Terrace only	8,233	<1	6,104	<1	14,337	<1
Terrace plus overland flow practice	0	0	49,249	1	49,249	<1
Filter only	696,139	24	2,129,652	42	2,825,791	36
Filter plus overland flow practice	316,595	11	643,736	13	960,332	12
Filter plus Terrace	32,260	1	99,226	2	131,486	2
Filter plus overland flow practice plus terrace	626,442	22	444,506	9	1,070,948	14
Buffer only	628,044	22	926,389	18	1,554,433	20
Buffer plus overland flow practice	196,128	7	197,799	4	393,927	5
Buffer plus Terrace	24,755	1	53,228	1	77,983	1
Buffer plus overland flow practice plus terrace	225,072	8	155,826	3	380,899	5
One or more additional practices	2,780,296	98	4,751,334	94	7,531,630	96
No structural practices	62,018	2	285,388	6	347,406	4
Total	2,842,314	100	5,036,722	100	7,879,035	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 about 10 percent of the acres (see table 9).

Specific rules for application timing

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

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

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

Specific rules for method of application

If the method of application was other than incorporation then in the simulation fertilizer and manure applications became incorporated or injected. Incorporation reduces the opportunity for nutrients on the soil surface to volatilize 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 ammonia 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.

Potential for Field-Level Gains

Treatment of the 2.84 million critical under-treated acres

According to the model simulation, treatment of the 2.84 million critical under-treated acres (acres with a “high” level of treatment need) with erosion control practices would nearly eliminate sediment loss for these acres and dramatically reduce nitrogen and phosphorus lost to surface water, as shown in table 33. Sediment loss would be reduced to an annual average of about 0.1 ton per acre per year for these acres, a 93-percent reduction. Nitrogen loss with surface runoff would be reduced to 2.4 pounds per acre per year on average (68-percent reduction), and phosphorus lost to surface water would be reduced to 1.6 pounds per acre per year (43-percent reduction). However, the re-routing of surface water to subsurface flow pathways would reduce nitrogen loss in subsurface flows by only 4 percent, on average, for these acres.

The addition of nutrient management had little additional effect on sediment loss or nitrogen loss with surface runoff, but was effective in reducing nitrogen loss in subsurface flows and phosphorus lost to surface water (table 33). Nitrogen loss in subsurface flows for these acres would be reduced 56 percent compared to losses simulated for the baseline conservation condition. Phosphorus lost to surface water would be reduced 63 percent compared to the baseline condition, bringing the average loss down to about 1 pound per acre for these acres.

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

Table 34 presents estimates of how treatment of only the 2.84 million critical under-treated acres in the region would reduce *overall* edge-of-field losses *for the region as a whole*. These results were obtained by combining treatment scenario model results for the 2.84 million acres with model results from the baseline conservation condition for the remaining acres.

Compared to the baseline conservation condition, treating the 2.84 million critical under-treated acres with soil erosion control practices *and* nutrient management practices would, for the region as a whole—

- reduce sediment loss in the region by 30 percent on average;
- reduce total nitrogen loss by 15 percent:
  - reduce nitrogen loss with surface runoff (sediment adsorbed and soluble) by 17 percent, and
  - reduce nitrogen loss in subsurface flows by 20 percent;
- reduce phosphorus lost to surface water (sediment adsorbed and soluble) by 16 percent; and
- reduce environmental risk from loss of pesticide residues by 5 to 10 percent.

Treatment of all 7.9 million under-treated acres

Simulation results for all the 7.9 million under-treated acres (acres with either a "high" or "moderate" level of treatment need) are presented in table 35 and results for the region as a whole are presented in table 36.

Table 35 shows that per-acre percent reductions of sediment and nutrient loss due to additional practices are about the same or less, on average, than percent reductions for the 2.84 million most vulnerable under-treated acres presented in table 33. The 7.9 million under-treated acres include 5.04 million acres with a moderate need for treatment that are less vulnerable or have more conservation practice use than the critical under-treated acres and therefore the potential for gains with additional treatment is less for those acres. The percent reductions *for the region as a whole* (table 36), however, are much higher than the percent reductions for treatment of only the 2.84 million critical under-treated acres shown in table 34.

Compared to the baseline conservation condition, treating all 7.9 million under-treated acres with soil erosion control practices *and* nutrient management practices would, for the region as a whole (table 36)—

- reduce sediment loss in the region by 64 percent on average;
- reduce total nitrogen loss by 31 percent:
  - reduce nitrogen loss with surface runoff (sediment adsorbed and soluble) by 42 percent, and
  - reduce nitrogen loss in subsurface flows by 38 percent;
- reduce phosphorus lost to surface water by 41 percent; and
- reduce environmental risk from loss of pesticide residues by 13 to 17 percent.

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, polymer coated products, nitrogen stabilizers, 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 soluble phosphorus loss; and
- Constructed wetlands receiving surface water runoff from farm fields prior to discharge to streams and rivers.

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

Table 33. Conservation practice effects for additional treatment of 2.84 million critical under-treated acres (acres with a high need for conservation treatment) in the Great Lakes Region

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)	4.1	3.7	11	3.7	11
Subsurface water flow (inches)	9.3	9.6	-3	9.6	-3
Erosion and sediment loss					
Wind erosion (tons/acre)	1.59	1.01	37	1.01	37
Sheet and rill erosion (tons/acre)	0.57	0.21	63	0.21	63
Sediment loss at edge of field due to water erosion (tons/acre)	1.07	0.07	93	0.07	93
Soil organic carbon					
Change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)	-155	-112	--	-118	--
Nitrogen					
Nitrogen applied (pounds/acre)	105	101*	4	64	39
Nitrogen in crop yield removed at harvest (pounds/acre)	90	87	3	84	6
Total nitrogen loss for all loss pathways (pounds/acre)	74.3	65.1	12	37.0	50
Loss of nitrogen with surface runoff, including waterborne sediment (pounds/acre)	7.5	2.4	68	2.1	72
Nitrogen loss in subsurface flows (pounds/acre)	48.7	46.7	4	21.4	56
Phosphorus					
Phosphorus applied (pounds/acre)	24.3	23.7*	2	18.1	25
Total phosphorus loss for all loss pathways (pounds/acre)	4.9	3.1	37	2.1	57
Loss of phosphorus to surface water, including waterborne sediment (pounds/acre)	2.7	1.6	43	1.0	63
Pesticide loss					
Mass loss of pesticides for all pathways (grams of active ingredient/hectare)	15.9	9.1	43	9.1	43
Surface water pesticide risk indicator for aquatic ecosystems	1.97	1.47	25	1.48	25
Surface water pesticide risk indicator for humans	0.61	0.40	35	0.39	36

* 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: Values reported in this table are for the 2.84 million critical under-treated acres only. Percent reductions are with respect to the baseline conservation condition.
Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text.

Table 34. Conservation practice effects for the region as a whole* after additional treatment of 2.84 million critical under-treated acres (acres with a high need for conservation treatment) in the Great Lakes Region

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)	4.5	4.4	2	4.4	2
Subsurface water flow (inches)	7.9	8.0	-1	8.0	-1
Erosion and sediment loss					
Wind erosion (tons/acre)	0.85	0.74	13	0.74	13
Sheet and rill erosion (tons/acre)	0.44	0.37	16	0.37	16
Sediment loss at edge of field due to water erosion (tons/acre)	0.63	0.44	30	0.44	30
Soil organic carbon					
Change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)	-58	-50	--	-51	--
Nitrogen					
Nitrogen applied (pounds/acre)	78	77**	1	70	10
Nitrogen in crop yield removed at harvest (pounds/acre)	96	95	1	94	1
Total nitrogen loss for all loss pathways (pounds/acre)	46.7	44.9	4	39.5	15
Loss of nitrogen with surface runoff, including waterborne sediment (pounds/acre)	6.1	5.1	16	5.0	17
Nitrogen loss in subsurface flows (pounds/acre)	25.8	25.4	1	20.6	20
Phosphorus					
Phosphorus applied (pounds/acre)	20.7	20.6**	1	19.5	6
Total phosphorus loss for all loss pathways (pounds/acre)	3.2	2.9	11	2.7	16
Loss of phosphorus to surface water, including waterborne sediment (pounds/acre)	2.1	1.9	11	1.8	16
Pesticide loss					
Mass loss of pesticides for all pathways (grams of active ingredient/hectare)	10.9	9.6	12	9.6	12
Surface water pesticide risk indicator for aquatic ecosystems	1.89	1.80	5	1.80	5
Surface water pesticide risk indicator for humans	0.44	0.40	9	0.40	10

* Results presented for the region as a whole combine model output for the 2.84 million 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.

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 additional treatment of 7.9 million under-treated acres (acres with a high or moderate need for conservation treatment) in the Great Lakes Region

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)	4.4	3.9	12	3.9	12
Subsurface water flow (inches)	8.3	8.6	-5	8.7	-5
Erosion and sediment loss					
Wind erosion (tons/acre)	1.04	0.72	31	0.71	32
Sheet and rill erosion (tons/acre)	0.55	0.23	59	0.23	59
Sediment loss at edge of field due to water erosion (tons/acre)	0.83	0.07	91	0.07	91
Soil organic carbon					
Change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)	-69	-35	--	-40	--
Nitrogen					
Nitrogen applied (pounds/acre)	96	93*	4	63	35
Nitrogen in crop yield removed at harvest (pounds/acre)	93	90	3	87	6
Total nitrogen loss for all loss pathways (pounds/acre)	59.2	52.7	11	31.8	46
Loss of nitrogen with surface runoff, including waterborne sediment (pounds/acre)	7.2	2.8	61	2.4	67
Nitrogen loss in subsurface flows (pounds/acre)	35.5	34.7	2	16.9	52
Phosphorus					
Phosphorus applied (pounds/acre)	23.4	22.9*	2	18.2	22
Total phosphorus loss for all loss pathways (pounds/acre)	4.1	2.8	32	1.9	54
Loss of phosphorus to surface water, including waterborne sediment (pounds/acre)	2.6	1.7	37	1.0	61
Pesticide loss					
Mass loss of pesticides for all pathways (grams of active ingredient/hectare)	12.3	7.9	36	7.8	36
Surface water pesticide risk indicator for aquatic ecosystems	1.99	1.54	23	1.54	23
Surface water pesticide risk indicator for humans	0.49	0.35	28	0.35	28

* 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: Values reported in this table are for the 7.9 million under-treated acres only. Percent reductions are with respect to the baseline conservation condition.

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

Table 36. Conservation practice effects for the region as a whole* after additional treatment of 7.9 million under-treated acres (acres with a high or moderate need for conservation treatment) in the Great Lakes Region

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)	4.5	4.2	6	4.2	6
Subsurface water flow (inches)	7.9	8.1	-3	8.2	-3
Erosion and sediment loss					
Wind erosion (tons/acre)	0.85	0.68	20	0.68	20
Sheet and rill erosion (tons/acre)	0.44	0.26	40	0.26	40
Sediment loss at edge of field due to water erosion (tons/acre)	0.63	0.23	64	0.23	64
Soil organic carbon					
Change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)	-58	-40	--	-43	--
Nitrogen					
Nitrogen applied (pounds/acre)	78	76**	2	60	23
Nitrogen in crop yield removed at harvest (pounds/acre)	96	94	2	92	3
Total nitrogen loss for all loss pathways (pounds/acre)	46.7	43.2	7	32.1	31
Loss of nitrogen with surface runoff, including waterborne sediment (pounds/acre)	6.1	3.7	38	3.5	42
Nitrogen loss in subsurface flows (pounds/acre)	25.8	25.4	2	16.0	38
Phosphorus					
Phosphorus applied (pounds/acre)	20.7	20.5**	1	18.0	13
Total phosphorus loss for all loss pathways (pounds/acre)	3.2	2.6	21	2.1	36
Loss of phosphorus to surface water, including waterborne sediment (pounds/acre)	2.1	1.6	25	1.2	41
Pesticide loss					
Mass loss of pesticides for all pathways (grams of active ingredient/hectare)	10.9	8.5	22	8.5	22
Surface water pesticide risk indicator for aquatic ecosystems	1.89	1.65	13	1.65	13
Surface water pesticide risk indicator for humans	0.44	0.37	16	0.37	17

* Results presented for the region as a whole combine model output for the 7.9 million 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.

Comparison of treatment scenario results

The distributions of sediment and nutrient losses for the two levels of treatment are compared to the baseline conservation condition in the Great Lakes Region in figures 68 through 73. 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 in the region by treating the under-treated acres. For example, 7 percent of the acres in the Great Lakes Region exceed an annual average loss of sediment of 2 tons per acre per year in the baseline conservation condition. Model simulations indicate that treating the most critical under-treated acres (2.84 million acres) with erosion control practices would reduce the acres exceeding sediment loss of 2 tons per acre per year to 4 percent (fig. 68). Expanding the treatment to include all under-treated acres (7.9 million acres) would further reduce the acres exceeding annual sediment loss of 2 tons per acre to 2 percent.

Similar effects of additional treatment are shown for wind erosion (fig. 69). Acres exceeding 4 tons per acre of wind erosion would be reduced from 5 percent for the baseline to 3 percent by treating the critical acres and to 2 percent by treating all under-treated acres.

Treatment of critical under-treated acres with erosion control and nutrient management would reduce the acres exceeding 15 pounds per acre of nitrogen lost with runoff from 7 percent for the baseline to 4 percent (fig. 70). Treatment of all 7.9 million under-treated acres would further reduce the percent losing more than 15 pounds per acre to 2 percent of cropped acres in the region.

For nitrogen loss in subsurface flow pathways, however, treatment of all 7.9 million under-treated acres would be required to reduce the overall regional edge-of-field losses to acceptable levels (fig. 71). About 28 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 2.84 million critical under-treated acres with nutrient management practices would reduce this percentage to 20 percent. Treatment of all 7.9 million under-treated acres would reduce the percentage to 11 percent.

For total nitrogen loss to all pathways, 43 percent of the acres in the baseline conservation condition exceed losses of 40 pounds per acre per year. Treating the most critical under-treated acres would reduce the acres exceeding this level of loss to 33 percent (fig. 72). Expanding the treatment to include all under-treated acres would further reduce the acres exceeding 40 pounds per acre to 17 percent.

Acres exceeding 4 pounds per acre of phosphorus lost to surface water would be reduced from 12 percent for the baseline to 10 percent by treating the critical acres and to 5 percent by treating all under-treated acres (fig. 73).

Soil organic carbon would be minimally affected by the additional soil erosion control and nutrient management practices. Increases in soil organic carbon would occur largely because of savings of carbon that would otherwise be lost from the field through wind and water erosion. Figure 74 shows that the percentage of acres building soil organic carbon would increase from 46 percent for the baseline conservation condition to 50 percent with additional conservation treatment of all the under-treated acres.

One of the objectives in constructing the treatment scenarios was to maintain the level of regional crop production. The removal of nitrogen at harvest serves as a useful proxy for crop yields and allows for aggregation over the mix of crops. The average annual amount of nitrogen removed at harvest would be reduced about 6 percent for the 7.9 million acres treated with additional soil erosion control and nutrient management practices (table 35), which represents a 3-percent reduction for the region as a whole (table 36). Figure 75 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.

Figure 68. Estimates of average annual sediment loss for under-treated acres treated with erosion control *and* nutrient management compared to the baseline conservation condition and the no-practice scenario, Great Lakes Region

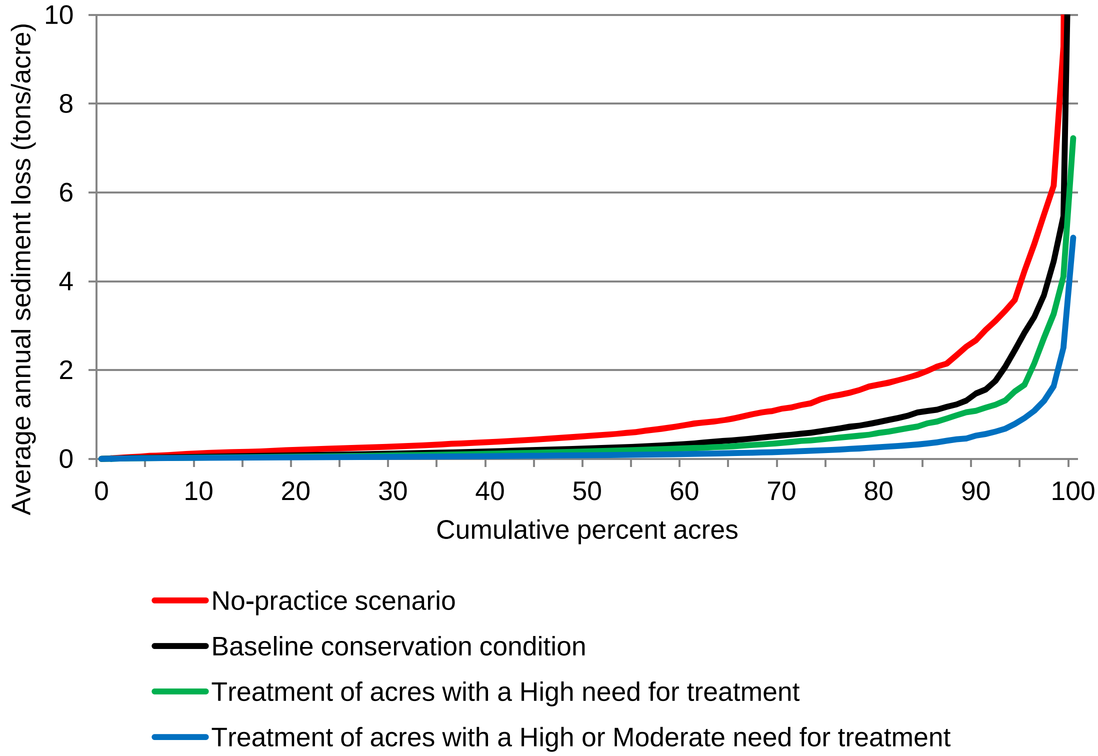


Figure 69. Estimates of average annual wind erosion for under-treated acres treated with erosion control *and* nutrient management compared to the baseline conservation condition and the no-practice scenario, Great Lakes Region

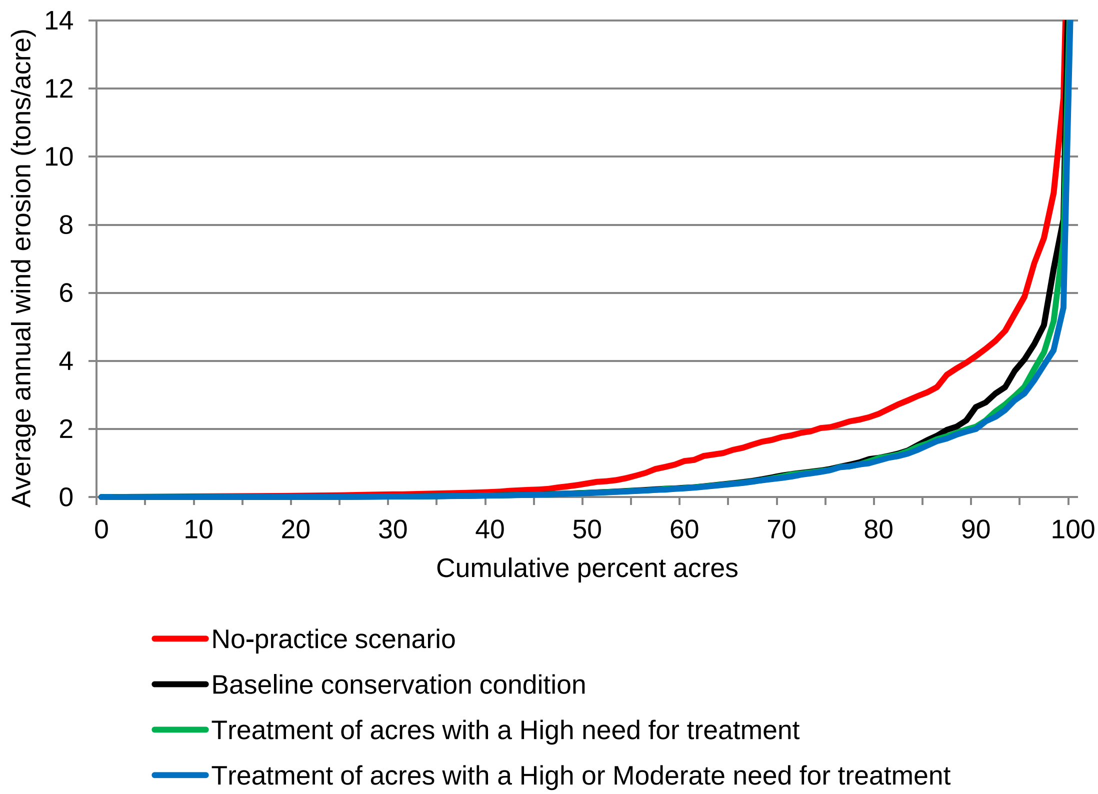


Figure 70. Estimates of average annual loss of nitrogen with surface runoff for under-treated acres treated with erosion control *and* nutrient management compared to the baseline conservation condition and the no-practice scenario, Great Lakes Region

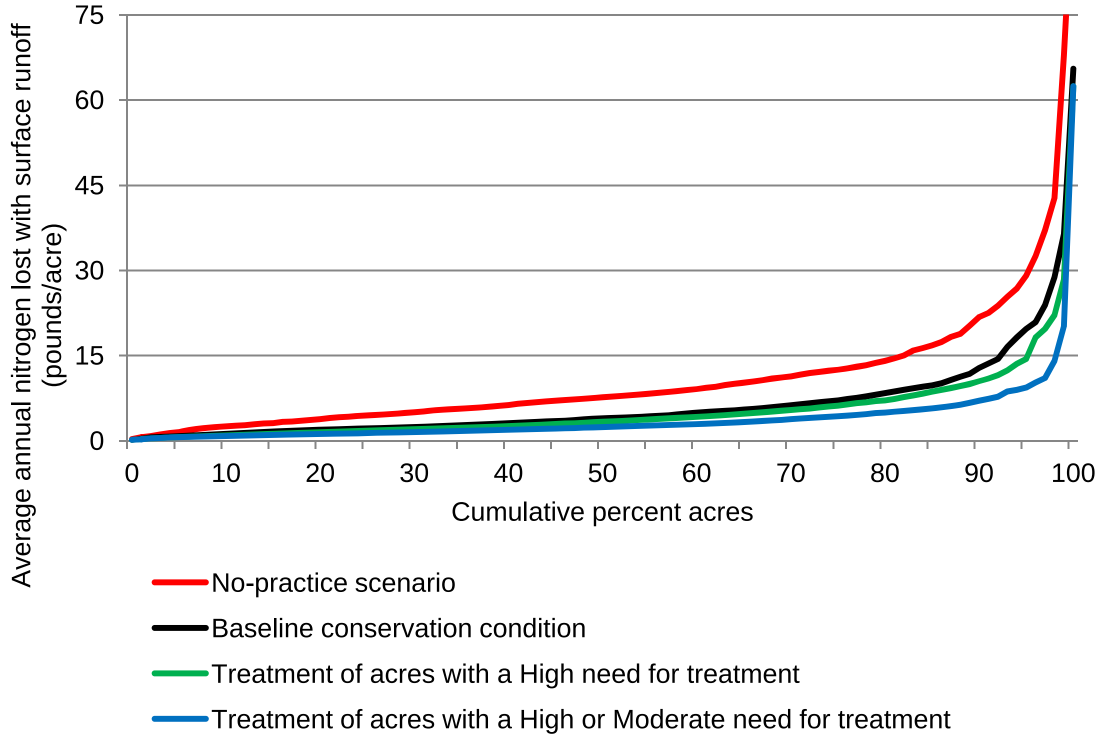


Figure 71. Estimates of average annual loss of nitrogen in subsurface flows for under-treated acres treated with erosion control *and* nutrient management compared to the baseline conservation condition and the no-practice scenario, Great Lakes Region

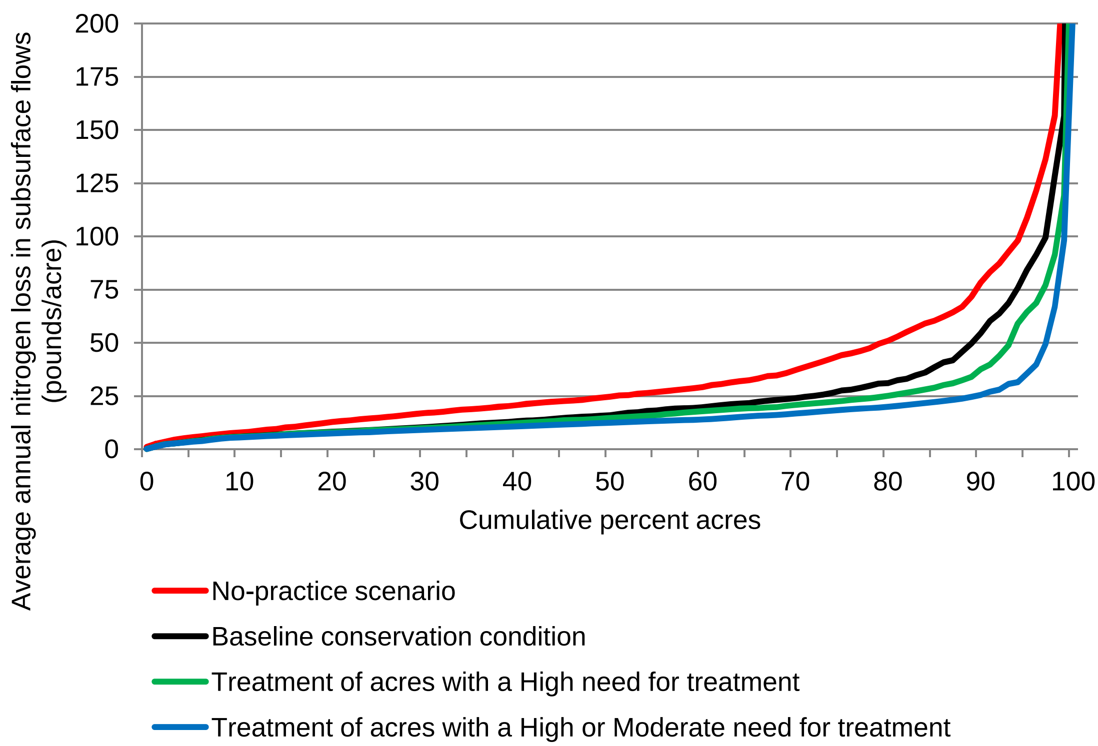


Figure 72. Estimates of average annual total nitrogen loss for under-treated acres treated with erosion control *and* nutrient management compared to the baseline conservation condition and the no-practice scenario, Great Lakes Region

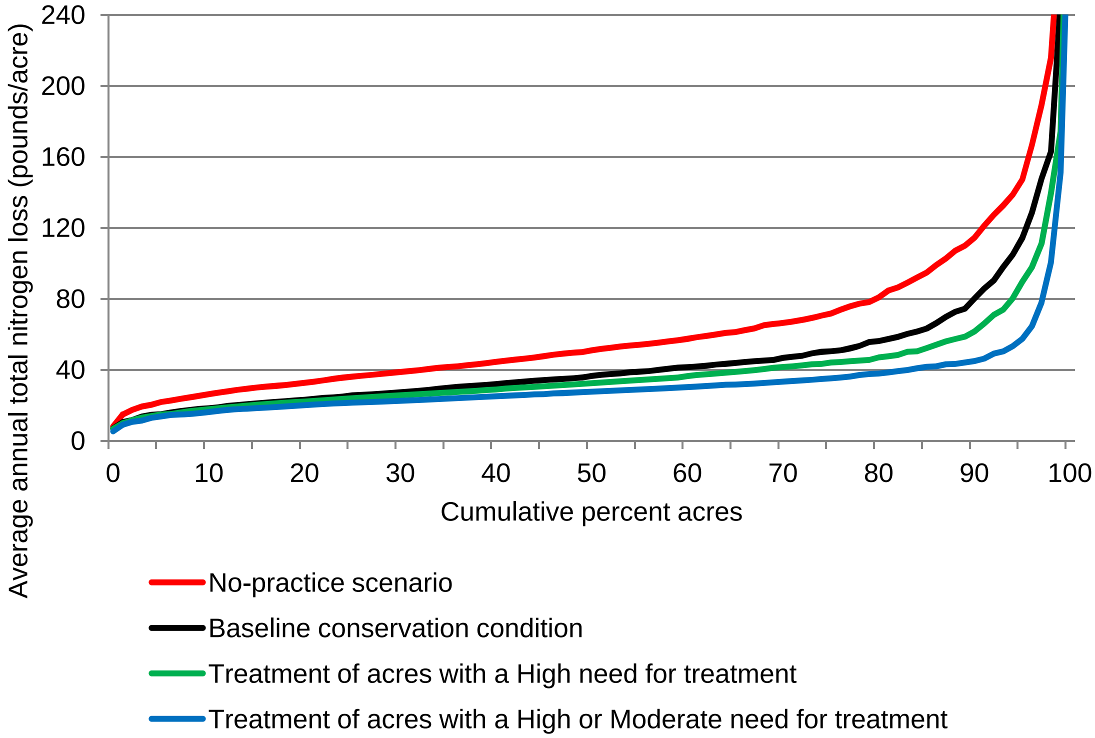
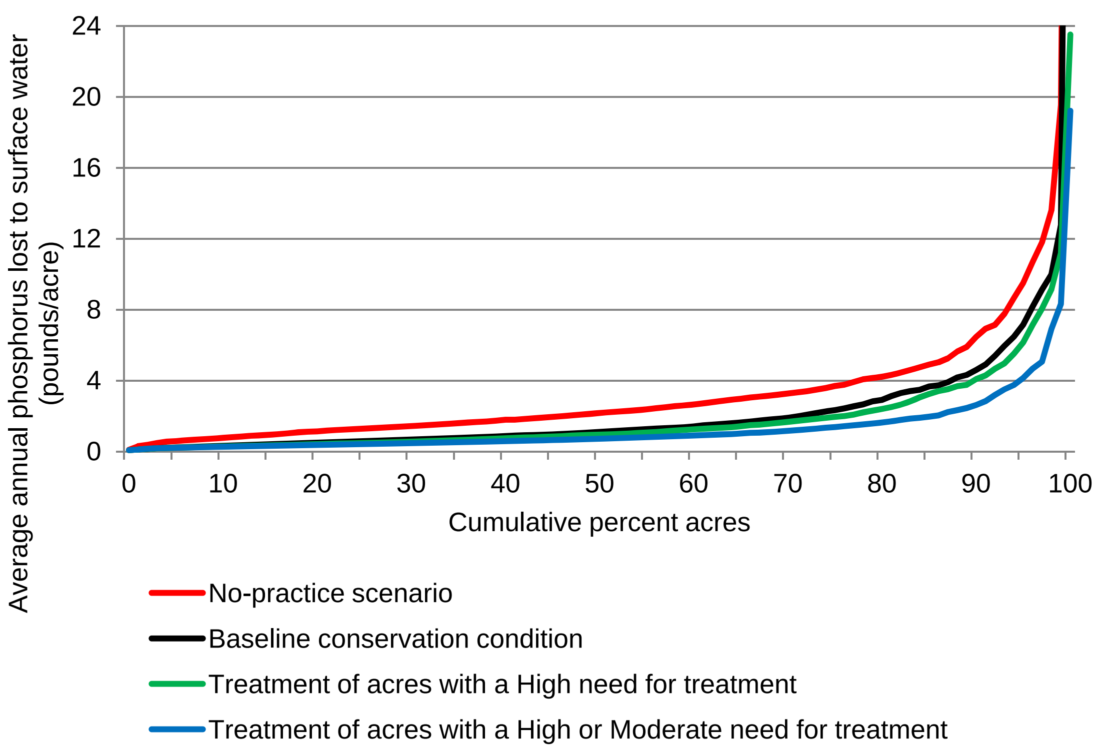


Figure 73. Estimates of average annual phosphorus lost to surface water (sediment attached and soluble)* for under-treated acres treated with erosion control *and* nutrient management compared to the baseline conservation condition and the no-practice scenario, Great Lakes Region



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

Figure 74. Estimates of average annual change in soil organic carbon for under-treated acres treated with erosion control *and* nutrient management compared to the baseline conservation condition and the no-practice scenario, Great Lakes Region

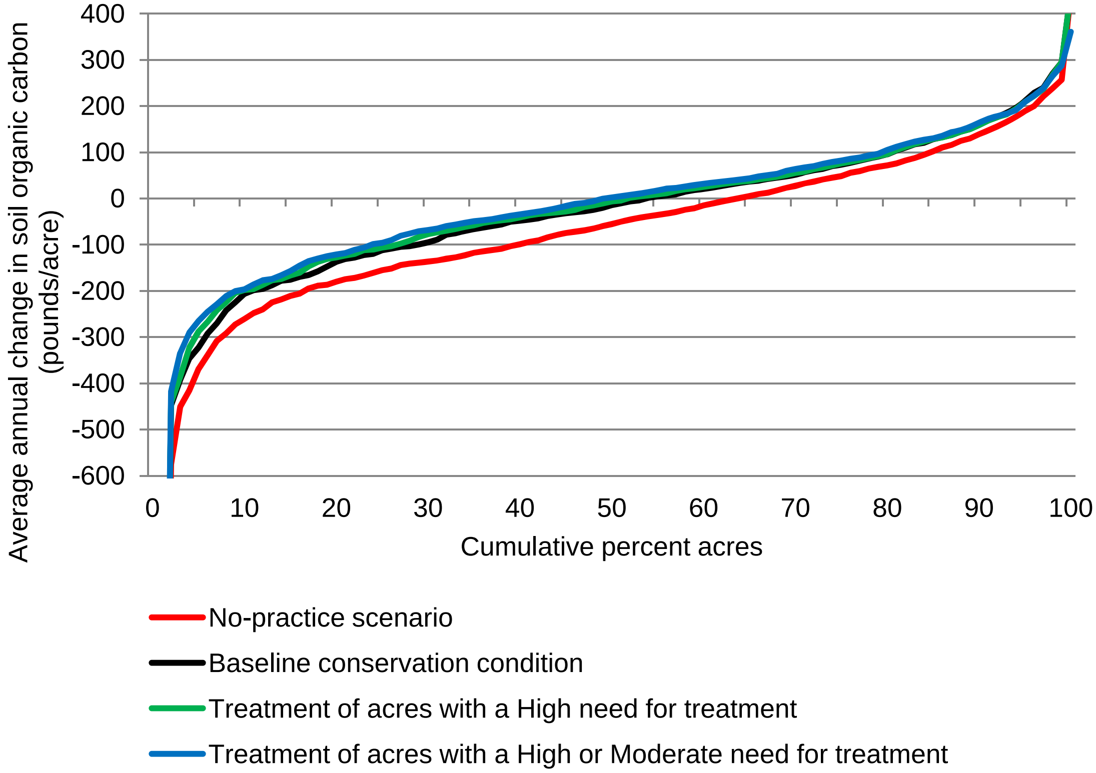
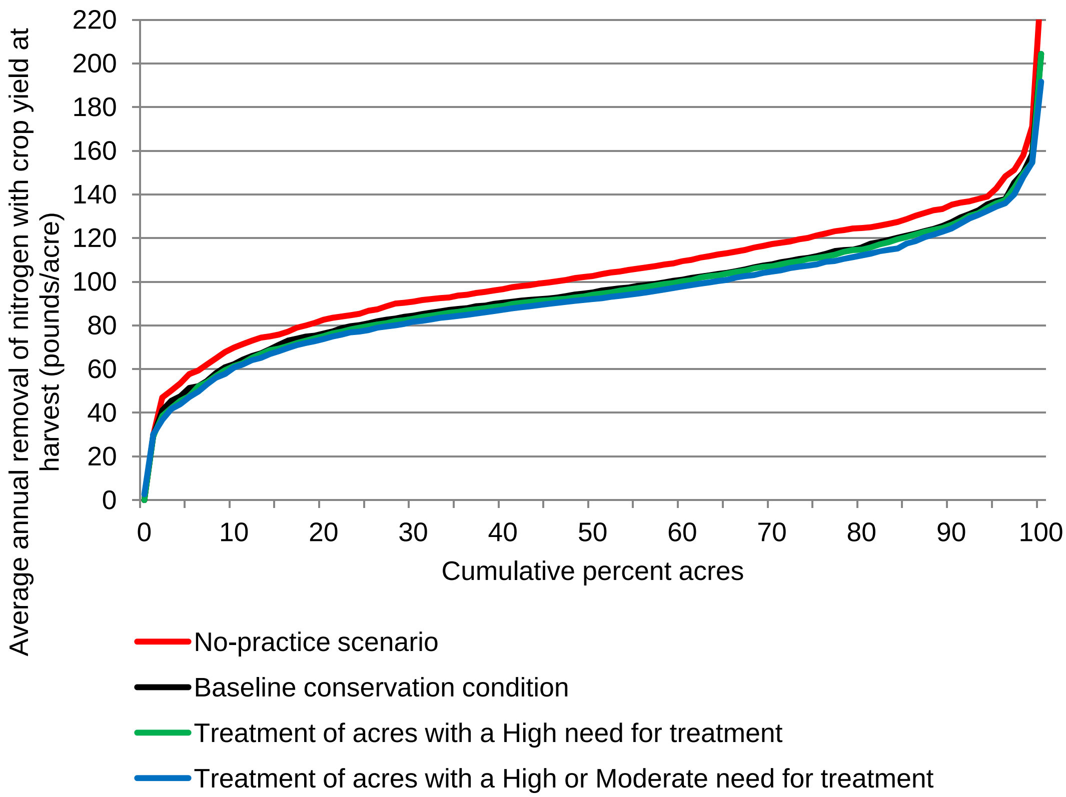


Figure 75. Estimates of average annual removal of nitrogen with crop yield at harvest for under-treated acres treated with erosion control *and* nutrient management compared to the baseline conservation condition and the no-practice scenario, Great Lakes Region



Diminishing returns from additional conservation treatment

Tables 33 through 36 and figures 68 through 73 suggest diminishing returns from additional conservation treatment when the most vulnerable acres are treated first. These diminishing returns are shown explicitly in table 37, which includes estimates of the effects of additional conservation practices on the 6.92 million adequately treated acres in the Great Lakes Region. Diminishing returns to additional conservation treatment is demonstrated by comparing the average annual per-acre reductions in loss among the three groups of acres.

For example, conservation treatment of the 2.84 million critical under-treated acres would reduce sediment loss an average of 1 ton per acre per year on those acres. In comparison, additional treatment of the 5.04 million under-treated acres with a moderate need for treatment would reduce sediment loss by about 0.63 ton per acre per year on those acres, and treatment of the remaining 6.92 million acres would reduce sediment loss by only 0.35 ton per acre per year on those acres, on average.

Wind erosion would be reduced by an average of 0.59 ton per acre per year on the 2.84 million critical under-treated acres, compared to a reduction of 0.18 ton per acre for the 5.04 million under-treated acres with a moderate need for treatment and 0.15 ton per acre for treatment of the remaining 6.92 million acres.

Similarly, diminishing returns were pronounced for nitrogen and phosphorus loss. Total nitrogen loss would be reduced by an average of 37 pounds per acre per year on the 2.84 million critical under-treated acres, compared to a reduction of 22 pounds per acre for the 5.04 million under-treated acres with a moderate need for treatment and only 6.5 pounds per acre for the remaining 6.92 million acres.

Nitrogen loss in subsurface flows would be reduced by an average of 27 pounds per acre per year on the 2.84 million critical under-treated acres, compared to a reduction of 14 pounds per acre for the 5.04 million under-treated acres with a moderate need for treatment. However, the reduction for treatment of the remaining 6.92 million acres would average only 2 pounds per acre.

Total phosphorus loss would be reduced by an average of 2.8 pounds per acre per year on the 2.84 million critical under-treated acres, compared to a reduction of 1.9 pounds per acre for the 5.04 million under-treated acres with a moderate need for treatment and only 0.9 pound per acre for the remaining 6.92 million acres.

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

(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 under-treated acres is substantially greater than the non-critical under-treated acres, the optimal strategy would be to treat a mix of critical and non-critical under-treated 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 need to also be considered, as well as any edge-of-field loss thresholds that would need to be met to achieve local water quality goals.)

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

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

The no-practice scenario represents the maximum losses that would be expected without any conservation practices in use. Treatment of *all acres* with nutrient management and 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 16.7 million tons of sediment, 263,037 tons of nitrogen, and 27,356 tons of phosphorus for the Great Lakes Region (fig. 76).

For sediment loss, about 50 percent of the potential savings are accounted for by the conservation practices already in use, as represented by the baseline conservation condition (fig. 76). Additional treatment of the 2.84 million critical under-treated acres would account for another 17 percent of the potential sediment savings. Treatment of the remaining 5.04 million under-treated acres would account for about 19 percent of the potential savings. Treatment of the 6.92 million adequately treated acres would account for the last 14 percent of potential savings.

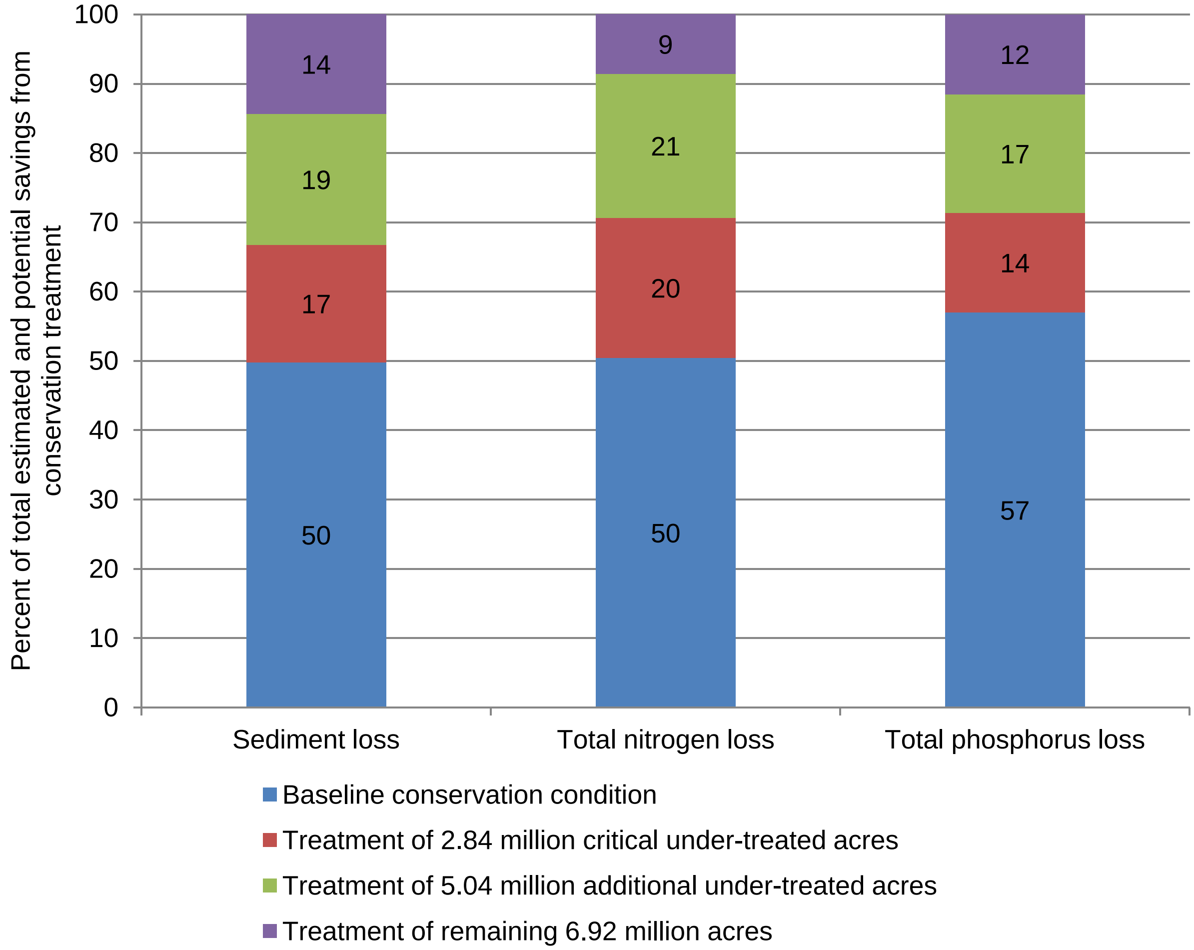
The proportions of savings from existing practices and projected savings with additional conservation treatment are about the same for nitrogen and sediment loss. Phosphorus savings are higher for existing practices, accounting for 57 percent of potential savings, with correspondingly less potential for additional savings with additional treatment (fig. 76).

Table 37. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices for three groups of acres comprising the 14.8 million cropped acres in the Great Lakes Region

	Additional treatment for 2.84 million critical under-treated acres*			Additional treatment for 5.04 million non-critical under-treated acres*			Additional treatment for remaining 6.92 million acres		
	Baseline	Treatment scenario		Baseline	Treatment scenario		Baseline	Treatment scenario	
	Average annual amount	Average annual amount	Reduction	Average annual amount	Average annual amount	Reduction	Average annual amount	Average annual amount	Reduction
Water flow									
Surface water runoff (inches)	4.1	3.7	0.4	4.6	4.0	0.5	4.5	4.0	0.6
Subsurface water flow (inches)	9.3	9.6	-0.3	7.7	8.2	-0.5	7.6	8.1	-0.5
Erosion and sediment loss									
Wind erosion (tons/acre)	1.59	1.01	0.587	0.72	0.54	0.181	0.64	0.50	0.146
Sheet and rill erosion (tons/acre)	0.57	0.21	0.36	0.55	0.24	0.31	0.31	0.15	0.16
Sediment loss at edge of field due to water erosion (tons/acre)	1.07	0.07	1.00	0.70	0.07	0.63	0.41	0.06	0.35
Soil organic carbon									
Change in soil organic carbon, including loss of carbon with wind and water erosion (pounds/acre)	-155	-118	37**	-21	4	25**	-46	-29	17**
Nitrogen									
Nitrogen applied (pounds/acre)	105	64	41	91	62	29	56	48	8
Nitrogen in crop yield removed at harvest (pounds/acre)	90	84	6	95	89	6	98	94	4
Total nitrogen loss for all loss pathways (pounds/acre)	74.3	37.0	37.4	50.7	28.9	21.7	32.4	25.9	6.5
Loss of nitrogen with surface runoff, including waterborne sediment (pounds/acre)	7.5	2.1	5.4	7.0	2.6	4.4	4.8	2.3	2.6
Nitrogen loss in subsurface flows (pounds/acre)	48.7	21.4	27.3	28.0	14.5	13.5	14.8	12.6	2.3
Phosphorus									
Phosphorus applied (pounds/acre)	24.3	18.1	6.2	22.9	18.3	4.6	17.7	15.4	2.3
Total phosphorus loss for all loss pathways (pounds/acre)	4.9	2.1	2.8	3.6	1.7	1.9	2.3	1.4	0.9
Loss of phosphorus to surface water, including waterborne sediment (pounds/acre)	2.7	1.0	1.7	2.6	1.0	1.5	1.5	0.7	0.7
Pesticide loss									
Mass loss of pesticides for all pathways (grams of active ingredient/hectare)	15.9	9.1	6.8	10.2	7.2	3.1	9.3	6.9	2.4
Surface water pesticide risk indicator for aquatic ecosystem	1.97	1.48	0.49	2.01	1.58	0.43	1.78	1.35	0.43
Surface water pesticide risk indicator for humans	0.61	0.39	0.22	0.41	0.32	0.09	0.38	0.29	0.10

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

Figure 76. 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 erosion control *and* nutrient management treatment of cropped acres in the Great Lakes Region



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

	Estimated savings due to conservation practice use (baseline conservation condition)	Potential savings from treatment of 2.84 million critical under-treated acres*	Potential savings from treatment of 5.04 million additional under-treated acres*	Potential savings from treatment of remaining 6.92 million acres*	Total estimated and potential savings from conservation treatment
Sediment	8,328,934	2,831,717	3,163,422	2,401,531	16,725,603
Nitrogen	132,648	53,111	54,714	22,564	263,037
Phosphorus	15,592	3,926	4,680	3,158	27,356

*Treatment with erosion control practices and nutrient management practices on all acres.
Note: Calculations do not include land in long-term conserving cover.
Note: Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

Chapter 7
Offsite Water Quality Effects of Conservation Practices

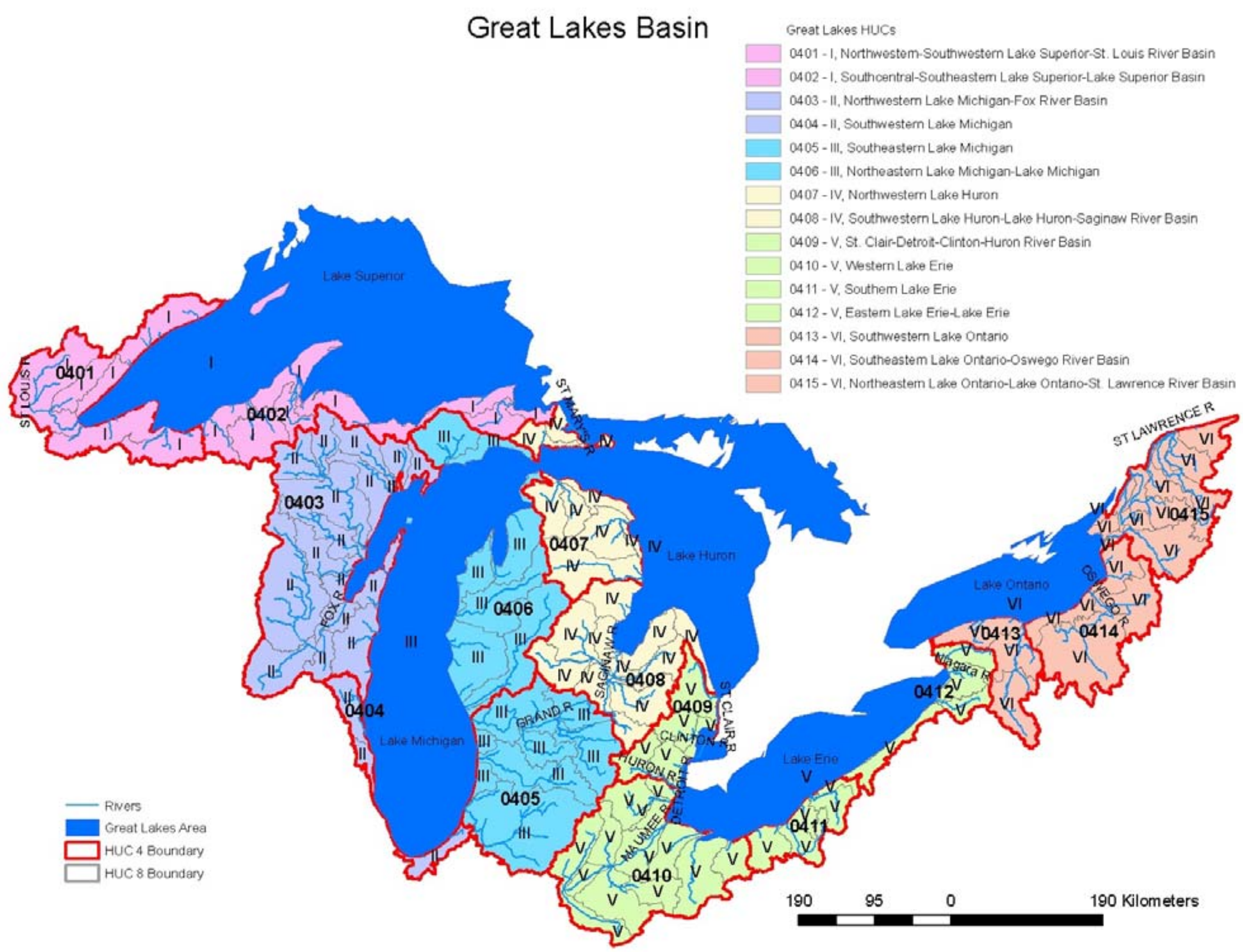
Field-level losses of sediment, nutrients, and pesticides estimated using APEX were integrated into a large-scale water quality model to estimate the water quality effects of conservation practices.

Results for the 15 subregions of the U.S. portion of the Great Lakes drainage are aggregated into six basins for reporting, designated using roman numerals as follows:

I	Lake Superior Basin including St. Louis River
II	Western Lake Michigan Basin including Fox River
III	Eastern Lake Michigan Basin
IV	Lake Huron Basin including Saginaw River
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers

Figure 77 shows the subregions and 8-digit HUCs included in each of the six basins.

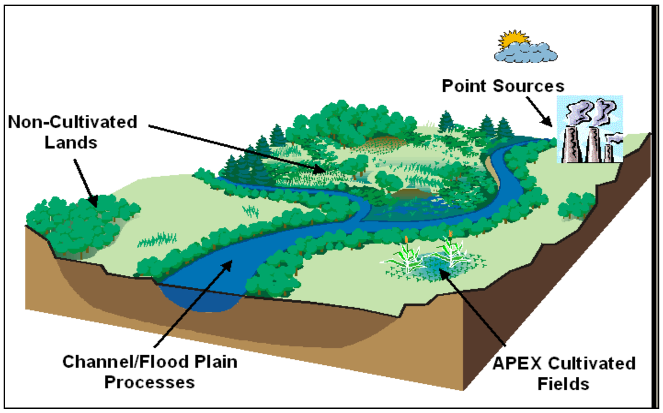
Figure 77. Subregions and 8-digit HUC groups used for reporting of source loads and instream loads for the six basins in the Great Lakes Region, U.S. portion of the drainage area



The National Water Quality Model—HUMUS/SWAT

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

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



Like APEX, SWAT is a physical process model with a daily time step (Arnold and Fohrer 2005; Arnold et al. 1998; Gassman et al. 2007).[21] The hydrologic cycle in the model is divided into two parts. The land phase of the hydrologic cycle, or upland processes, simulates the amount of water, sediment, nutrients, and pesticides delivered from the land to the outlet of each watershed. The routing phase of the hydrologic cycle, or channel processes, simulates the movement of water, sediment, nutrients, and pesticides from the outlet of the upstream watershed through the main channel network to the watershed outlet.

Upland processes

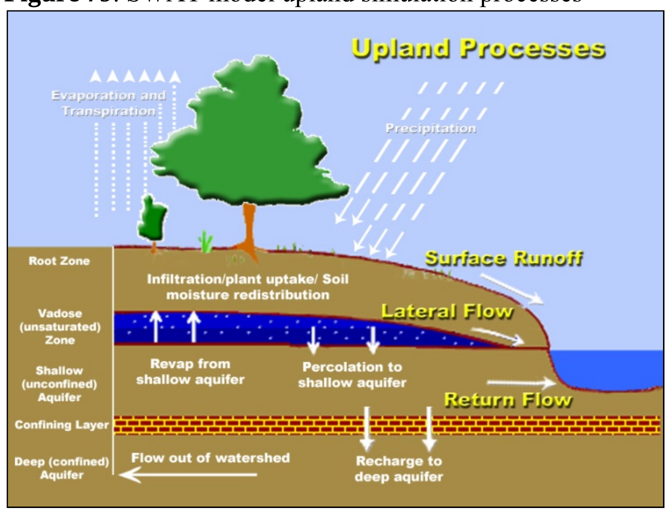
The water balance is the driving force for transport and delivery of sediment, nutrients, and pesticides from fields to streams and rivers. For this study, upland processes for non-cultivated cropland were modeled using SWAT, while source loads for cultivated cropland are estimated by APEX.

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

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

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

Figure 79. SWAT model upland simulation processes



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

Various types of land management activities were modeled in SWAT for agricultural land. For permanent hayland, the following management activities were simulated:

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

- Hay was fertilized with nitrogen according to the crop need as determined by an auto-fertilization routine, which was set to grow the crop without undue nitrogen stress.
- Legume hay was grown in a 4-year rotation and phosphorus was applied at the time of planting (every fourth year) at a rate of 50 pounds per acre, followed by applications of 13 pounds per acre every other year.
- Manure was applied to hayland at rates estimated from probable land application of manure from animal feeding operations, estimated using the methods described in USDA/NRCS (2003).
- Three hay cuttings were simulated per crop year for grass hay and four hay cuttings were simulated per year for legume hay.
- For hayland acres that land-use databases indicated were irrigated, water was applied at a frequency and rate defined by an auto-irrigation routine.

For pastureland and rangeland, the following management activities were simulated:

- Continuous grazing was simulated by algorithms that determined the length of the grazing period, amount of biomass removed, and the amount of biomass trampled. Grazing occurs whenever the plant biomass is above a specified minimum plant biomass for grazing. The amount of biomass trampled daily is converted to residue.
- Manure nutrients from grazing animals were simulated for pastureland according to the density of pastured livestock as reported in the 2002 Census of Agriculture. Non-recoverable manure was estimated by subtracting recoverable manure available for land application from the total manure nutrients representing all livestock populations. Non-recoverable manure nutrients include the non-recoverable portion from animal feeding operations. Estimates of manure nutrients were derived from data on livestock populations as reported in the 2002 Census of Agriculture, which were available for each 6-digit HUC and distributed among the 8-digit HUCs on a per-acre basis.
- Manure was applied to pastureland and rangeland at rates estimated from probable land application of manure obtained from animal feeding operations as estimated in USDA/NRCS (2003).
- Supplemental commercial nitrogen fertilizers were applied to pastureland according to the crop need as determined by an auto-fertilization routine, which was set to grow grass without undue nitrogen stress.

Horticulture land was fertilized with 100 pounds per acre of nitrogen per year and 44 pounds per acre of phosphorus. For the irrigated horticultural acres, water was applied at a frequency and rate defined by an auto-irrigation routine.

Land application of biosolids from wastewater treatment facilities was not simulated. Manure nutrients from wildlife populations are not included in the model simulation.

A summary of the total amount of nitrogen and phosphorus applied to agricultural land in the model simulation, including nitrogen and phosphorus applied to cultivated cropland in the APEX modeling, is presented in table 38.[22]

Urban Sources

Urban sources include (1) loads from point sources discharged from industrial and municipal wastewater treatment plants and (2) loads from urban runoff.

Discharges from industrial and municipal wastewater treatment plants can be major sources of nutrients and sediment in some watersheds. Point sources of water flow, total suspended sediment, total phosphorus, and Kjeldahl nitrogen were estimated using county-level data on population change to adjust 1980 estimates of point source loadings published by Resources for the Future (Gianessi and Peskin 1984) to the year 2000. The original Resources for the Future assessment covered 32,000 facilities, including industries, municipal wastewater treatment plants, and small sanitary waste facilities for the years 1977 to 1981. A GIS-based procedure was used to convert county data to the 8-digit HUC level. Point source loads are aggregated within each watershed and average annual loads input into SWAT at the watershed outlet.

Urban runoff is estimated separately for three categories of cover within an urban HRU: 1) Pervious surfaces such as lawns, golf courses, and gardens, 2) impervious surfaces hydraulically connected to drainage systems such as paved roads and paved streets draining to storm drains, and 3) impervious surfaces not hydraulically connected to drainage systems such as a house roof draining to a pervious yard that is not directly connected to drains (composite urban surface consisting of impervious roof surface and pervious yard surface).

Pervious surfaces are simulated in the same manner as other grass areas (such as pasture). Surface runoff from pervious surfaces is calculated using the curve number. Nitrogen fertilizer (40 pounds per acre per year) is applied on grassed urban area such as lawns and grassed roadsides using an auto-fertilizer routine to grow grass without undue nitrogen stress. The grass is considered irrigated as needed based on plant stress demand using an auto-irrigation routine.

Point source phosphorus loads were provided by Dave Baker (Heidelberg University, Ohio) and David Dolan (University of Wisconsin) for the Lake Erie Basin. These data were for the 2003 calendar year, but average loads were similar for the period 2001 to 2005. These data provided estimates of phosphorus loads by discharger, which were aggregated to the 8-digit HUC level and incorporated into the CEAP framework.

---

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

Table 38. Summary of commercial fertilizer and manure nutrients applied to agricultural land in HUMUS/SWAT (pastureland, rangeland, hayland, and horticulture) and APEX (cultivated cropland) models, Great Lakes Region.

4-digit HUC group*	Basins within Great Lakes Region	Commercial nitrogen fertilizer (tons/year)	Nitrogen from manure (tons/year)	Total nitrogen (tons/year)	Commercial phosphorus fertilizer (tons/year)	Phosphorus from manure (tons/year)	Total phosphorus (tons/year)
				Cultivated cropland			
I	Lake Superior Basin including St. Louis River	0	164	164	0	88	88
II	Western Lake Michigan Basin including Fox River	58,578	30,205	88,782	12,685	10,514	23,200
III	Eastern Lake Michigan Basin	111,573	15,212	126,785	25,595	5,388	30,983
IV	Lake Huron Basin including Saginaw River	71,790	11,212	83,002	15,234	4,033	19,267
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	193,868	14,754	208,622	54,040	5,914	59,955
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	40,782	22,380	63,162	10,568	8,476	19,043
	Total	476,591	93,927	570,518	118,122	34,413	152,535
				Hayland			
I	Lake Superior Basin including St. Louis River	3,530	106	3,635	202	46	248
II	Western Lake Michigan Basin including Fox River	17	210	227	2,737	96	2,832
III	Eastern Lake Michigan Basin	1,859	354	2,213	2,333	175	2,508
IV	Lake Huron Basin including Saginaw River	1,046	126	1,171	1,280	55	1,335
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	4,261	254	4,515	1,275	115	1,389
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	16,424	1,214	17,638	1,786	516	2,301
	Total	27,137	2,264	29,400	9,612	1,002	10,614
				Pastureland and rangeland			
I	Lake Superior Basin including St. Louis River	321	1,292	1,613	159	638	796
II	Western Lake Michigan Basin including Fox River	5,198	20,886	26,084	1,728	6,951	8,678
III	Eastern Lake Michigan Basin	4,783	19,877	24,660	1,766	7,423	9,189
IV	Lake Huron Basin including Saginaw River	1,738	7,197	8,935	649	2,677	3,327
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	3,707	15,029	18,736	1,289	5,239	6,529
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	4,445	18,362	22,807	1,530	6,359	7,889
	Total	20,193	82,642	102,835	7,121	29,287	36,408

* See text and figure 77 for groupings of 8-digit and 4-digit HUCs for reporting.
Note: The amounts reported in this table are as elemental nitrogen and elemental phosphorus (not fertilizer equivalents).

Table 38--continued. Summary of commercial fertilizer and manure nutrients applied to agricultural land in HUMUS/SWAT (pastureland, rangeland, hayland, and horticulture) and APEX (cultivated cropland) models, Great Lakes Region.

4-digit HUC group*	Basins within Great Lakes Region	Commercial nitrogen fertilizer (tons/year)	Nitrogen from manure (tons/year)	Total nitrogen (tons/year)	Commercial phosphorus fertilizer (tons/year)	Phosphorus from manure (tons/year)	Total phosphorus (tons/year)
				Horticulture			
I	Lake Superior Basin including St. Louis River	46	0	46	20	0	20
II	Western Lake Michigan Basin including Fox River	718	0	718	316	0	316
III	Eastern Lake Michigan Basin	7,469	0	7,469	3,288	0	3,288
IV	Lake Huron Basin including Saginaw River	465	0	465	205	0	205
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	2,572	0	2,572	1,132	0	1,132
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	2,817	0	2,817	1,240	0	1,240
	Total	14,086	0	14,086	6,200	0	6,200
				Total for all agricultural land			
I	Lake Superior Basin including St. Louis River	3,897	1,561	5,458	381	772	1,153
II	Western Lake Michigan Basin including Fox River	64,510	51,301	115,812	17,466	17,561	35,026
III	Eastern Lake Michigan Basin	125,684	35,443	161,126	32,981	12,987	45,968
IV	Lake Huron Basin including Saginaw River	75,040	18,534	93,574	17,369	6,765	24,133
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	204,408	30,037	234,445	57,736	11,268	69,004
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	64,467	41,956	106,424	15,123	15,350	30,473
	Total	538,006	178,833	716,839	141,055	64,702	205,757

For estimating surface water runoff from impervious urban areas, a runoff curve number of 98 was used for surfaces connected hydraulically to drainage systems. A composite runoff curve number was used for impervious surfaces not hydraulically connected to drainage systems. Sediment and nutrients carried with storm water runoff to streams and rivers were estimated using the build up-wash off algorithm developed by Huber and Dickinson (1988).

The concept behind the buildup-wash off algorithm is that over a period of time, dust, dirt and other constituents are built up on street surfaces during dry periods. During a storm event the materials are washed off. The built-up wash-off algorithms are developed from an EPA national urban water quality database that relates storm runoff loads to rainfall, drainage area and impervious area.

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

A summary of the total amount of nitrogen and phosphorus applied to non-agricultural land in the model simulation is presented in table 39.

Nutrients from septic systems were not included in the model simulations as data on locations of septic systems, populations using the septic systems, and types of septic systems were not available.

Table 39. Summary of nutrients applied to urban land, nutrients originating from point sources, and wet and dry atmospheric deposition of nitrogen used as inputs to the HUMUS/SWAT model, Great Lakes Region

		Urban land	Point sources		Wet and dry atmospheric deposition
4-digit HUC group*	Basins within Great Lakes Region	Nitrogen fertilizer (tons/year)	Nitrogen (tons/year)	Phosphorus (tons/year)	Nitrogen (tons/year)
I	Lake Superior Basin including St. Louis River	3,541	3,003	623	56,231
II	Western Lake Michigan Basin including Fox River	10,757	20,574	1,949	38,511
III	Eastern Lake Michigan Basin	25,542	12,134	935	83,092
IV	Lake Huron Basin including Saginaw River	9,155	9,967	1,063	50,925
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	26,964	74,695	2,222	34,369
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	7,263	16,976	2,944	46,390
	Total	83,221	137,347	9,736	309,518

Note: The amounts reported in this table are as elemental nitrogen and elemental phosphorus (not fertilizer equivalents).

Atmospheric nitrogen deposition

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

Routing and channel processes

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

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

- **Sediment routing—deposition, bed degradation, and streambank erosion**. Sediment transport in the stream network is a function of two processes, deposition and degradation. SWAT computes deposition and degradation simultaneously within the reach. Deposition is based on the fall velocity of the sediment particles and the travel time through each stream. Stream power is used to predict bed and bank degradation; excess stream power results in degradation. Bed degradation and streambank erosion are based on the erodibility and vegetative cover of the bed or bank and the energy available to carry sediment (a function of depth, velocity and slope). The maximum amount of sediment that can be transported from a reach segment is a function of the peak channel velocity. Available stream power is used to re-entrain loose and deposited material until all of the material is removed.[23]

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

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

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

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

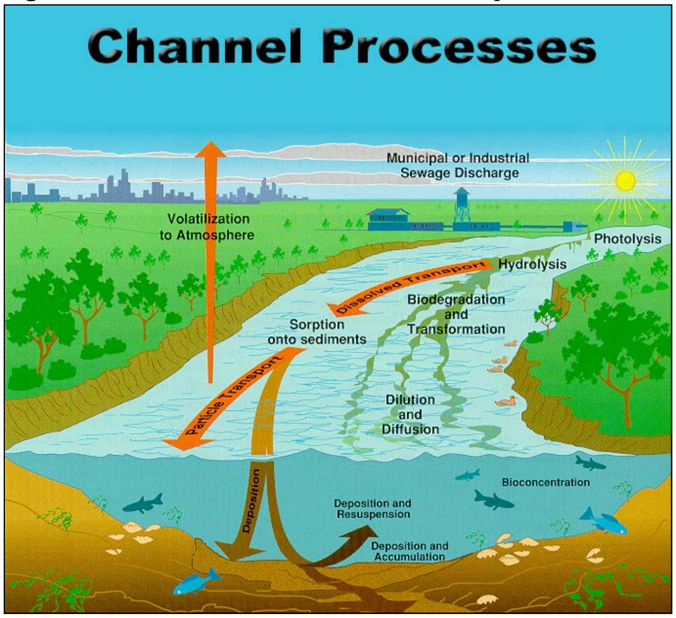
- **Sediment routing**. The concentration of sediment in the reservoir is estimated using a simple continuity equation based on volume and concentration of inflow, outflow, and water retained in the reservoir. Settling of sediment in the reservoir is governed by an equilibrium sediment concentration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

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

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

[23] There are no national estimates of streambank erosion that can be uniformly used to calibrate this component of the model. Parameters governing instream sediment processes are adjusted in concert with those governing upland sediment yields such that HUMUS predictions at calibration sites mimic measured sediment data. Sediment data collected at a single stream gauging site is a combination of upland and instream sources, which cannot be proportioned by source. Collectively a network of sediment monitoring sites may be used to develop a sediment budget for a watershed which may include a streambank component. When such studies are available for a HUMUS region they are used as ancillary data during model calibration.

Figure 80. SWAT model channel simulation processes



Calibration

Delivery of surface water and subsurface water from upland processes (HRUs and CEAP sample points) was spatially calibrated for each subregion to ensure that streamflow was in agreement with long-term average runoff for the region. Hydrologic parameters in APEX (cultivated cropland) and SWAT (other HRUs) were adjusted separately for each 8-digit watershed until differences in the long-term water yield were minimized. Time series of predicted annual and monthly streamflow were compared against the monitored counterpart. If necessary, the channel losses, seepage, and evaporation losses in reservoirs were adjusted to match the predicted flow time series with that of observed data. The calibration period is from 1961-1990 and the validation period from 1991-2006. Most of the flow calibration was carried out for the upland runoff with minimal or no parameterization for the time series of annual and monthly streamflow. [24]

For sediment calibration, observations were taken from USGS monitoring stations. Most of the sediment observations were grab sample concentrations of suspended sediment. These, along with monitored daily flow data were processed using a load estimator or load runner program to estimate annual average sediment load. The estimated annual average sediment load was used to validate the predicted sediment load from HUMUS. In the Great Lakes Region, predicted sediment was calibrated/validated to match the observations collected at five different gauging stations. Of the five stations, data for three were from USGS-NASQAN program. Data for the remaining two stations came from the Water Quality Lab of Heidelberg University.

[24] For a complete documentation of calibration procedures and results for the Great Lakes Region, see "Calibration and Validation of CEAP HUMUS" at http://www.nrcs.usda.gov/technical/nri/ceap.

For calibration of upland soil erosion, soil erodibility factor and residue cover were adjusted. For calibration of instream sediment load, parameters controlling stream power and sediment carrying capacity of the channel were adjusted. Delivery ratios from field to 8-digit watershed and 8-digit watershed to river were adjusted to match predicted sediment load with that of observations for each validation station. Where necessary, parameters affecting settling of sediment in reservoirs were also adjusted.

Five gauging stations (the same as for sediment calibration) were selected in the Great Lakes Region for nutrient calibration. Most of the data for nutrient calibration were taken from the USGS-NASQAN data monitoring program. Nutrient observations were available for the St Louis, Fox, Saginaw, Maumee, and Cuyahoga Rivers. For the Maumee River and Cuyahoga River, nutrient concentrations obtained from the Water Quality Lab at Heidelberg University were used. Nutrient loads were estimated from grab sample concentrations using the same procedure described for sediment.

For calibration of upland nutrient load, parameters controlling nutrient uptake by plants, leaching to groundwater and mineralization were adjusted. For calibration of instream nutrient load, parameters affecting benthic source rate, mineralization, hydrolysis and settling with sediment were adjusted. Where necessary, parameters affecting settling of nutrients in reservoirs were also adjusted.

Data available for atrazine calibration are limited. The calibration data were from a single USGS monitoring station on the Maumee River. Only the soluble form of atrazine is calibrated because atrazine is most likely to appear in soluble form rather than with sediment. The delivery ratio and in-stream parameters controlling decay, settling, burial and resuspension of atrazine were adjusted to match predicted atrazine load with that of observations.

The "background" scenario

An additional scenario was conducted to represent loadings that would be expected if no acres in the watershed were cultivated. These estimates were derived by simulating with APEX a grass-and-tree mix cover without any tillage or addition of nutrients or pesticides for all cultivated cropland acres in the watershed.[25] All SWAT modeling remained the same for this scenario. Thus, "background" loads include

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

loads from all other land uses—hayland, pastureland, rangeland, horticulture, forestland, and urban land—as well as point sources.

Source Loads and Instream Loads

All source loads are introduced into SWAT at the outlet of each watershed (8-digit hydrologic unit code [HUC]). Flows and source loads from upstream watersheds are routed through each downstream watershed, including reservoirs when present. [26]

A sediment delivery ratio was used to account for deposition in ditches, floodplains, and tributary stream channels during transit from the edge of the field to the outlet. The sediment delivery ratio used in this study is a function of the ratio of the time of concentration for the HRU (land uses other than cultivated cropland) or field (cultivated cropland) to the time of concentration for the watershed (8-digit HUC). The time of concentration for the watershed is the time from when a surface water runoff event occurs at the most distant point in the watershed to the time the surface water runoff reaches the outlet of the watershed. It is calculated by summing the overland flow time (the time it takes for flow from the remotest point in the watershed to reach the channel) and the channel flow time (the time it takes for flow in the upstream channels to reach the outlet). The time of concentration for the field is derived from APEX. The time of concentration for the HRU is derived from characteristics of the watershed, the HRU, and the proportion of total acres represented by the HRU. Consequently, each cultivated cropland sample point has a unique delivery ratio within each watershed, as does each HRU.[27]

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

A separate delivery ratio is used to simulate the transport of nitrate nitrogen, soluble phosphorus, and soluble pesticides. In general, the proportion of soluble nutrients and pesticides delivered to rivers and streams is higher than the proportion attached to sediments because they are not subject to sediment deposition.

There are four points in the modeling process at which source loads or instream loads are assessed, shown in the schematic in figure 81 for sediment.

1. Edge-of-field loads from cultivated cropland—aggregated APEX model output as reported in the previous chapter.

2. Delivery to the watershed outlet from cultivated cropland—aggregated edge-of-field loads after application of delivery ratios. Loadings delivered to streams and rivers differ from the amount leaving the field because of losses during transport from the field to the stream. Delivery ratios are used to make this adjustment.

3. Delivery to the watershed outlet from land uses other than cultivated cropland as simulated by SWAT, after application of delivery ratios. Point sources are included

4. Loadings in the stream or river at a given point. Instream loads include loadings delivered to the watershed outlet from all sources as well as loads delivered from upstream watersheds, after accounting for channel and reservoir processes.

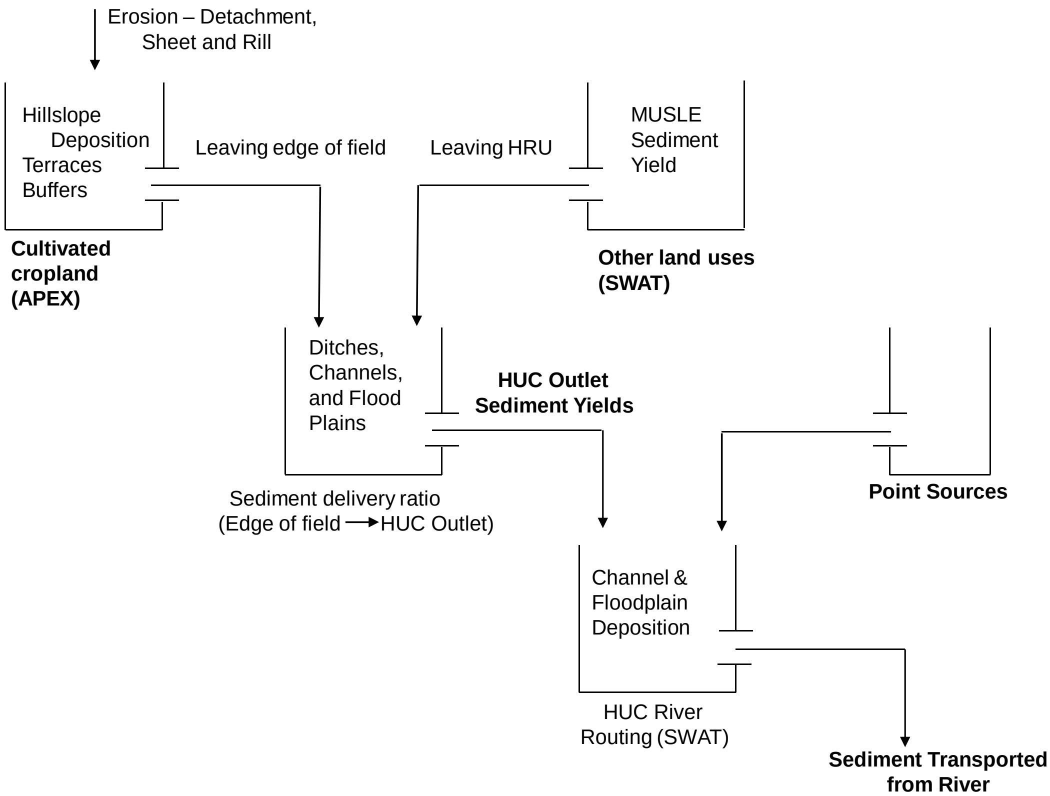
For reporting, edge-of-field loads, source loads, and instream loads were aggregated over the 4-digit HUCs to the six basins shown in figure 77.

---

[26] For a complete documentation of HUMUS/SWAT as it was used in this study, see "The HUMUS/SWAT National Water Quality Modeling System and Databases" at http://www.nrcs.usda.gov/technical/nri/ceap.

[27] For a complete documentation of delivery ratios used for the Great Lakes Region, see "Delivery Ratios Used in CEAP Cropland Modeling" at http://www.nrcs.usda.gov/technical/nri/ceap.

Figure 81. Schematic of sediment sources and delivery as modeled with HUMUS/SWAT for the Great Lakes Region



"Legacy Phosphorus" Not Accounted for in Modeling

"Legacy phosphorus" results from the over-application of phosphorus on farm fields in past years. When excessive amounts of fertilizer or manure are applied to a farm field, soil phosphorus levels increase dramatically. It may take many years or even decades for phosphorus levels to return to background levels once these practices are halted. Use of soil testing to determine the need for phosphorus applications can prevent further over-application, but there remains other phosphorus material locked into the soil profile within the field, along the edge of the field and drainageways, and in streambeds that cannot be offset by current management activities.

In addition, the transport of sediment—and the phosphorus bound to those particles—from farm fields to rivers and streams can take many years. Eroded soil particles leaving a farm field can be deposited where runoff slows or ponding occurs before reaching a stream or river. Once the sediment has entered streams, some of the soil particles settle out and can remain in the streambed or settle on the floodplain when the water is high and slow moving. These sediments can remain in place for years until a storm creates enough surface water runoff to re-suspend the previously eroded soil, or until streamflow cuts into streambanks made up of deposits of previously eroded soil. Windborne sediment transported into waterways can similarly be a mixture of newly eroded and previously eroded materials.

Consequently, the phosphorus content of eroded soil from farm fields can be high even when excessive amounts of fertilizer or manure are no longer being applied, including eroded soil from land that is not currently farmed. The measured phosphorus levels in rivers and streams include not only phosphorus lost from farm fields as a result of current farming activities but also "legacy phosphorus" adsorbed to soil particles as a result of prior farming activities. Some of this sediment-adsorbed "legacy phosphorus" can be solubilized by chemical reactions within the water body and measured as soluble phosphorus.

The simulation models used in this study do not account for these "legacy phosphorus" levels. There is recognition, however, that "legacy phosphorus" can be an important contributor to current levels of instream phosphorus loads, including soluble phosphorus loads.

Modeling Land Use in the Great Lakes Region

The USGS National Land-Cover Database for 2001 (Homer et al. 2007) was the principal source of acreage for HUMUS/SWAT modeling. The 2003 National Resources Inventory (USDA-NRCS 2007) was used to adjust NLCD cropland acreage estimates to include acres in Conservation Reserve Program General Signups, used here to represent cropland in long-term conserving cover. Consequently, cultivated cropland acres used to simulate the water quality effects of conservation practices differ slightly from the cropped acres reported in the previous chapters, which were estimated on the basis of the CEAP Cropland sample.

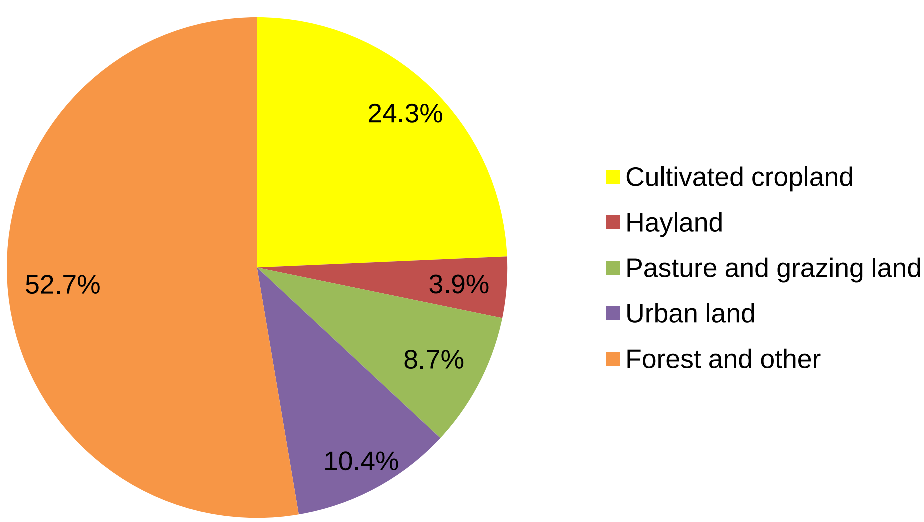
Estimates of the acreage by land use used to estimate the effects of conservation practices in this chapter are presented in table 40 and figure 82. Over 60 percent of the cultivated cropland acres are in two of the six Lake basins—the Lake Erie basin with 6.8 million acres (38.2 percent of the region total) and the Eastern Lake Michigan basin with 4.0 million acres (22.7 percent of the region total) (table 40). The Lake Superior basin has very little cultivated cropland, and the Lake Ontario basin has less than 1.5 million acres. The highest concentration of cultivated cropland is in the Western Lake Erie subregion (code 410) with 7.7 million cultivated cropland acres—73 percent of the total acres in the subregion (table 4).

Table 40. Acres by land use, exclusive of water, used in model simulations to estimate instream sediment, nutrient, and atrazine loads for the Great Lakes Region

4-digit HUC group*	Basins within Great Lakes Region	Cultivated cropland (acres)*	Hay land not in rotation with crops (acres)	Pasture and grazing land not in rotation with crops (acres)**	Urban land (acres)	Forest and other (acres)***	Total land (acres)****
I	Lake Superior Basin including St. Louis River	118,439	145,868	474,801	331,866	9,438,303	10,509,278
II	Western Lake Michigan Basin including Fox River	3,069,223	600,315	577,231	1,149,975	7,444,238	12,840,983
III	Eastern Lake Michigan Basin	4,040,566	566,733	1,699,820	1,736,932	7,097,839	15,141,890
IV	Lake Huron Basin including Saginaw River	2,370,965	317,723	1,188,481	966,208	5,328,731	10,172,109
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	6,800,246	399,586	825,075	2,794,711	2,896,815	13,716,433
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	1,417,924	856,658	1,611,527	655,102	6,422,842	10,964,053
	Regional total	17,817,364	2,886,885	6,376,936	7,634,794	38,628,767	73,344,746

*Acres of cultivated cropland include land in long-term conserving cover as well as hay land and pastureland in rotation with crops.
**Includes grass and brush rangeland categories.
***Includes forests (all types), wetlands, horticulture, and barren land.
****Exclusive of water.
Note: See text and figure 77 for groupings of 8-digit and 4-digit HUCs for reporting. Estimates were obtained from HUMUS databases on land use, and thus cultivated cropland estimates do not exactly match the acreage estimates obtained from the NRI-CEAP sample.

Figure 82. Percent acres for land use/cover types in the Great Lakes Region, exclusive of water



Conservation Practice Effects on Water Quality

HUMUS/SWAT accounts for the transport of water, sediment, pesticides, and nutrients from the land to receiving streams and routes the flow downstream to the next watershed and ultimately to estuaries and oceans. Not all of the sediment, nutrients, and pesticides that leave farm fields is delivered to streams and rivers. Some material is bound up in various parts of the landscape during transport. In addition, instream degradation processes and streambed deposition and accumulation remove or trap a portion of the sediment, nutrients, and pesticides after delivery to streams and rivers.

The results from the onsite APEX model simulations for cultivated cropland, including land in long-term conserving cover, were integrated into HUMUS/SWAT to assess the effects of conservation practices on instream loads of sediment, nitrogen, phosphorus, and atrazine. The effects of conservation practices on water quality were assessed by comparing HUMUS/SWAT model simulation results for the baseline conservation condition to simulation results for the no-practice scenario.

For the no-practice scenario, only the conditions for cultivated cropland were changed, as described previously. All other aspects of the simulations—including sediment and nutrient loads from point sources and land uses other than cultivated cropland—remained the same.

In summary, findings for the Great Lakes Region indicate that for the baseline conservation condition—

- *Amounts of sediment, nutrients, and atrazine loads* ***delivered to rivers and streams from cultivated cropland sources*** *per year, on average, are:*
  - *4.1 million tons of sediment (43 percent of loads from all sources);*
  - *930 million pounds of nitrogen (45 percent of loads from all sources);*
  - *48 million pounds of phosphorus (47 percent of loads from all sources); and*
  - *47,000 pounds of atrazine.*

- *Instream* ***loads from all sources delivered from the region to the Lakes*** *per year, on average, are:*
  - *8.9 million tons of sediment (15 percent attributable to cultivated cropland sources);*
  - *836 million pounds of nitrogen (43 percent attributable to cultivated cropland sources);*
  - *38 million tons of phosphorus (43 percent attributable to cultivated cropland sources); and*
  - *40,000 pounds of atrazine;*

Conservation practices in use on cultivated cropland in 2003-06, including land in long-term conserving cover, have—

- *Reduced sediment, nutrient, and atrazine loads* ***delivered to rivers and streams from cultivated cropland sources*** *per year, on average, by:*
  - *50 percent for sediment;*
  - *37 percent for nitrogen;*
  - *36 percent for phosphorus, and*
  - *24 percent for atrazine.*

- *Reduced instream* ***loads from all sources delivered from the region to the Lakes*** *per year, on average, by:*
  - *12 percent for sediment;*
  - *21 percent for nitrogen;*
  - *20 percent for phosphorus, and*
  - *23 percent for atrazine.*

Sediment

Baseline condition. Model simulation results show that of the 10.8 million tons of sediment exported from farm fields in the Great Lakes Region (table 41), about 4 million tons are delivered to rivers and streams each year (table 42), on average, under conditions represented by the baseline conservation condition, which simulates farming activities and conservation practices in use during the period 2003–06.

Most (about 79 percent) of the sediment from cultivated cropland originates in three basins—the Lake Erie basin, theWestern Lake Michigan basin, and the Lake Ontario basin (table 41). On a per-acre basis, sediment delivery is highest in the Lake Ontario basin, averaging 1.7 tons per cultivated cropland acre lost at the edge of the field and 0.7 tons per acre delivered to rivers and streams (tables 41 and 42). Among the remaining basins, per-acre sediment loss is highest for the Western Lake Michigan basin, averaging 0.8 ton lost at the edge of the field and 0.3 ton delivered to rivers and streams (tables 41 and 42).

Sediment delivered to rivers and streams from cultivated cropland represents about 35 percent of the total sediment load delivered from all sources in the region (table 43, fig. 83). This percentage ranges from 4 percent in the Lake Superior basin to 59 percent in the Western Lake Michigan basin (table 43). Urban nonpoint sources accounted for 24 percent of the total sediment load delivered from all sources to rivers and streams in the region. Urban nonpoint sources were highest in the Lake Erie basin, accounting for 35 percent of the sediment load delivered to rivers and streams in that basin.

Instream loads—the amount of sediment delivered from all sources to the Lakes after accounting for instream deposition and transport processes—total about 9 million tons per year, averaged over the 47 years of weather as simulated in the model (table 44). Of this, about 15 percent is attributed to cultivated cropland sources in the model simulation. The amount attributed to cultivated cropland was determined by subtracting the loads delivered to the Lakes in the "background" scenario (no cultivation) from the total load from all sources in the baseline conservation scenario (table 44).

Lake Erie receives the most sediment—3.3 million tons per year, on average. However, only 13 percent of this is attributable to cultivated cropland sources (table 44, fig. 84). The two Lake Michigan basins each deliver about the same amount of sediment to Lake Michigan (1.1–1.2 million tons per year), but the largest share is attributable to cultivated cropland sources in the Western Lake Michigan basin (28 percent). Lake Ontario receives 1.5 million tons of sediment per year, of which 22 percent is attributable to cultivated cropland sources.

Effects of conservation practices. Sediment loads delivered to streams and rivers would have been much larger if soil erosion control practices were not in use. Model simulations indicate that conservation practices have reduced the delivery of sediment from fields to rivers and streams by about 50 percent (table 42), on average. Reductions due to conservation practices varied among the six basins, ranging from 42 percent for the Lake Ontario basin to 56 percent for the Eastern Lake Michigan basin.

Model simulations of instream loads indicate that conservation practices have reduced the delivery of sediment to the Lakes by about 12 percent overall (table 44). Without conservation practices, the total sediment delivered to the Lakes would be larger by 1.2 million tons (table 44 and fig. 84) per year. The largest percent reduction in loads delivered to the Lakes was in the Western Lake Michigan basin—20 percent.

Table 41. Average annual sediment loads ***delivered to edge of field*** (APEX model output) from cultivated cropland in the Great Lakes Region

4-digit HUC group*	Basins within Great Lakes Region	Baseline conservation condition: Amount (1,000 tons)	Baseline conservation condition: Percent of basin total	Baseline conservation condition: Tons delivered per cultivated cropland acre	No-practice Scenario (1,000 tons)	Reductions in loads due to conservation practices: Reduction (1,000 tons)	Reductions in loads due to conservation practices: Percent
I	Lake Superior Basin including St. Louis River	60	<1	0.49	106	46	43
II	Western Lake Michigan Basin including Fox River	2,575	24	0.82	4,712	2,136	45
III	Eastern Lake Michigan Basin	1,787	17	0.45	3,973	2,185	55
IV	Lake Huron Basin including Saginaw River	600	6	0.25	1,070	470	44
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	3,404	32	0.49	7,518	4,114	55
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	2,372	22	1.72	4,714	2,341	50
	Regional total	10,800	100	0.60	22,090	11,290	51

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Loads represent both cropped acres and land in long-term conserving cover. Some columns do not add to totals because of rounding.
*See figure 77.

Table 42. Average annual sediment loads ***delivered to watershed outlets*** (8-digit HUCs) ***from cultivated cropland*** in the Great Lakes Region

4-digit HUC group*	Basins within Great Lakes Region	Baseline conservation condition: Amount (1,000 tons)	Baseline conservation condition: Percent of basin total	Baseline conservation condition: Tons delivered per cultivated cropland acre	No-practice Scenario (1,000 tons)	Reductions in loads due to conservation practices: Reduction (1,000 tons)	Reductions in loads due to conservation practices: Percent
I	Lake Superior Basin including St. Louis River	22	<1	0.17	39	17	44
II	Western Lake Michigan Basin including Fox River	971	24	0.31	1,815	844	47
III	Eastern Lake Michigan Basin	605	15	0.15	1,363	758	56
IV	Lake Huron Basin including Saginaw River	241	6	0.10	440	200	45
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	1,326	32	0.19	2,970	1,643	55
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	922	23	0.67	1,581	659	42
	Regional total	4,086	100	0.23	8,208	4,121	50

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. The differences between loadings in this table and table 42 are due to the application of delivery ratios, which were used to simulate delivery of sediment from the edge of the field to the watershed outlet (8-digit HUC). Some columns do not add to totals because of rounding.
*See figure 77.

Table 43. Average annual sediment loads ***delivered to watershed outlets*** (8-digit HUCs***) from all sources*** in the Great Lakes Region, baseline conservation condition, by source

4-digit HUC group*	Basins within Great Lakes Region	All sources	Cultivated cropland*	Hayland	Pasture and grazing land	Urban: Nonpoint sources**	Urban: Point sources	Forest and other***
	Amount (1,000 tons)							
I	Lake Superior Basin including St. Louis River	582	22	12	32	103	14	399
II	Western Lake Michigan Basin including Fox River	1,644	971	63	29	286	47	249
III	Eastern Lake Michigan Basin	1,571	605	55	106	441	14	350
IV	Lake Huron Basin including Saginaw River	869	241	34	69	267	12	248
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	2,744	1,326	96	52	949	206	115
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	2,022	922	354	125	264	40	317
	Regional total	9,433	4,086	614	413	2,310	332	1,678
	Percent of all sources							
I	Lake Superior Basin including St. Louis River	100	4	2	6	18	2	58
II	Western Lake Michigan Basin including Fox River	100	59	4	2	17	3	13
III	Eastern Lake Michigan Basin	100	39	4	7	28	1	18
IV	Lake Huron Basin including Saginaw River	100	28	4	8	31	1	22
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	100	48	3	2	35	8	3
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	100	46	17	6	13	2	14
	Regional total	100	43	7	4	24	4	14

* Includes land in long-term conserving cover, excludes horticulture.
** Includes construction sources and urban land runoff.
*** Includes forests (all types), wetlands, horticulture, and barren land.

Figure 83. Percentage by source of average annual sediment loads delivered to rivers and streams in the Great Lakes Region, baseline conservation condition

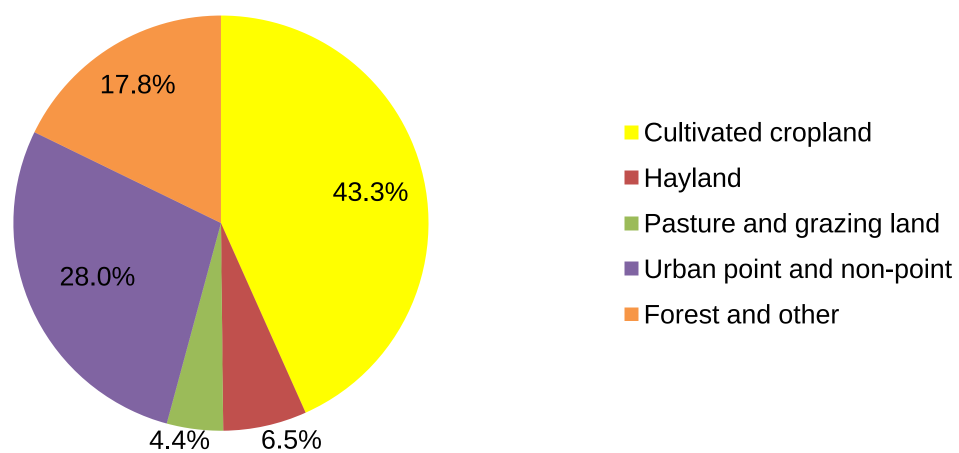


Table 44. Average annual ***instream sediment loads*** (all sources) delivered to the Great Lakes

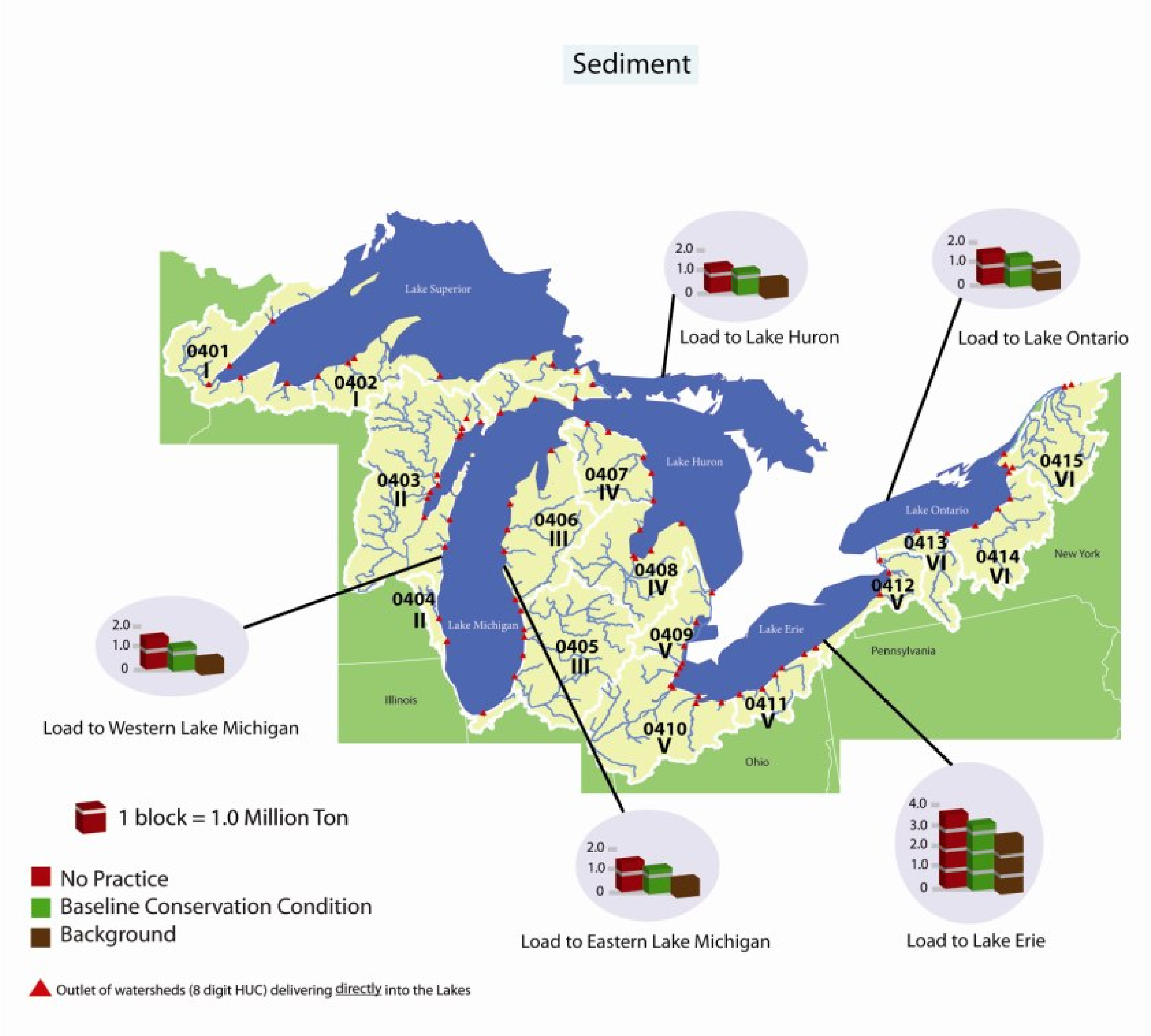
4-digit HUC group*	Basins within Great Lakes Region	**Baseline conservation condition** Load from all sources (1,000 tons)	Background sources** (1,000 tons)	Percent of load attributed to cultivated cropland sources	No-practice scenario (1,000 tons)	**Reductions in loads due to conservation practices** Reduction (1,000 tons)	Percent
I	Lake Superior Basin including St. Louis River	728	714	2	739	11	2
II	Western Lake Michigan Basin including Fox River	1,115	799	28	1,386	271	20
III	Eastern Lake Michigan Basin	1,127	938	17	1,333	206	15
IV	Lake Huron Basin including Saginaw River	1,053	981	7	1,135	82	7
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	3,374	2,943	13	3,828	454	12
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	1,525	1,189	22	1,737	212	12
	Regional total	8,922	7,564	15	10,158	1,236	12

*See figure 77.

** "Background sources" represent loadings that would be expected if no acres in the watershed were cultivated. These estimates were derived by running an additional scenario that simulated a grass and tree mix cover without any tillage or addition of nutrients or pesticides for all cultivated cropland acres in the watershed.

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

Figure 84. Estimates of average annual instream sediment loads for the baseline conservation condition compared to the no-practice scenario for the Great Lakes Region*



* Instream sediment loads delivered to the Great Lakes (all sources) are shown for each basin , corresponding to estimates presented in table 44.

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

Total Nitrogen

Baseline condition. Model simulation results show that about 463 million pounds of nitrogen are lost from farm fields (edge-of-field) per year within the Great Lakes Region (table 45) under conditions represented by the baseline conservation condition, which includes farming activities and conservation practices in use during the period 2003–06. Of this, about 418 million pounds are delivered into rivers and streams, on average (table 46).

The most nitrogen delivered to rivers and streams is in the Lake Erie basin (133 million pounds per year, 32 percent of the total), followed by the Eastern Lake Michigan basin (91 million pounds per year, 22 percent of the total) (table 46). On a per-acre basis, however, nitrogen delivery is highest in the Lake Ontario basin, averaging 49 pounds per cultivated cropland acre lost at the edge of the field and 43 pounds per acre delivered to rivers and streams (tables 45 and 46). Among the remaining basins, per-acre nitrogen loss ranged from 22 to 29 pounds lost at the edge of the field and 21 to 28 pounds delivered to rivers and streams (tables 45 and 46).

Nitrogen delivered to rivers and streams from cultivated cropland represents about 45 percent of the total nitrogen load delivered from all sources (table 47, fig. 85). This percentage ranges from 13 percent in the Lake Superior basin to 53 percent in the Lake Huron basin (table 47).

Urban sources (point sources and nonpoint sources) accounted for 33 percent of the total nitrogen load delivered from all sources to rivers and streams in the region. Urban sources were highest in the Lake Erie basin, accounting for 45 percent of the nitrogen load delivered to rivers and streams in the basin, slightly less than from cultivated cropland at 47 percent. In all but the Lake Superior basin, nitrogen loads delivered to rivers and streams from cultivated cropland exceed nitrogen from urban runoff and point sources.

Instream loads—the amount of nitrogen delivered from all sources to the Lakes after accounting for instream deposition and transport processes—total about 836 million pounds per year, averaged over the 47 years of weather as simulated in the model (table 48). Of this, about 43 percent is attributed to cultivated cropland sources in the model simulation. The amount attributed to cultivated cropland was determined by subtracting the loads delivered to the Lakes in the "background" scenario (no cultivation) from the total load from all sources in the baseline conservation scenario (table 48). About 52 percent of the instream nitrogen load from all sources delivered to Lake Huron is attributed to cultivated cropland sources.

Lake Michigan receives the most nitrogen from all sources—307 million pounds per year, on average, with 65 percent coming from the Eastern Lake Michigan basin. About 40 percent of instream loads delivered to Lake Michigan are attributable to cultivated cropland sources. Lake Erie receives almost as much nitrogen—276 million pounds per year, with 45 percent attributable to cultivated cropland sources.

Effects of conservation practices. Conservation practices in use throughout the watershed have reduced nitrogen loads, but not as dramatically as sediment loads. Model simulations indicate that conservation practices have reduced the delivery of nitrogen from fields to rivers and streams by about 37 percent (table 46), on average. Reductions due to conservation practices varied among the six basins, ranging from 32 percent for the Lake Huron basin to 47 percent for the Lake Superior basin.

Model simulations of instream loads indicate that conservation practices have reduced the delivery of nitrogen to the Lakes by about 21 percent overall (table 48). Without conservation practices, the total nitrogen delivered to the Lakes would be larger by 216 million pounds per year (table 48, figure 86). The largest percent reductions in loads delivered to the Lakes are in the Eastern Lake Michigan basin and the Lake Huron basin—24 percent.

Table 45. Average annual nitrogen loads ***delivered to edge of field*** (APEX model output) from cultivated cropland in the Great Lakes Region

4-digit HUC group*	Basins within Great Lakes Region	Baseline conservation condition: Amount (1,000 pounds)	Baseline conservation condition: Percent of basin total	Baseline conservation condition: Pounds delivered per cropland acre	No-practice Scenario (1,000 pounds)	Reductions in loads due to conservation practices: Reduction (1,000 pounds)	Reductions in loads due to conservation practices: Percent
I	Lake Superior Basin including St. Louis River	3,377	<1	27.3	6,325	2,948	47
II	Western Lake Michigan Basin including Fox River	74,650	16	23.9	131,400	56,720	43
III	Eastern Lake Michigan Basin	99,110	21	24.9	164,700	65,580	40
IV	Lake Huron Basin including Saginaw River	69,100	15	28.9	107,800	38,680	36
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	148,700	32	21.5	214,600	65,890	31
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	68,180	15	49.4	104,400	36,210	35
	Regional total	463,100	100	25.8	729,200	266,000	36

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Loads represent both cropped acres and land in long-term conserving cover. Some columns do not add to totals because of rounding.
*See figure 77.

Table 46. Average annual nitrogen loads ***delivered to watershed outlets*** (8-digit HUCs) ***from cultivated cropland*** in the Great Lakes Region

4-digit HUC group*	Basins within Great Lakes Region	Baseline conservation condition: Amount (1,000 pounds)	Baseline conservation condition: Percent of basin total	Baseline conservation condition: Pounds delivered per cropland acre	No-practice Scenario (1,000 pounds)	Reductions in loads due to conservation practices: Reduction (1,000 pounds)	Reductions in loads due to conservation practices: Percent
I	Lake Superior Basin including St. Louis River	3,192	<1	25.8	6,071	2,880	47
II	Western Lake Michigan Basin including Fox River	65,050	16	20.8	116,600	51,510	44
III	Eastern Lake Michigan Basin	90,972	22	22.8	153,100	62,150	41
IV	Lake Huron Basin including Saginaw River	66,541	16	27.8	104,800	38,260	37
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	132,863	32	19.2	194,300	61,410	32
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	59,769	14	43.3	92,020	32,260	35
	Regional total	418,397	100	23.3	666,900	248,500	37

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. The differences between loadings in this table and table 45 are due to the application of delivery ratios, which were used to simulate delivery of nitrogen from the edge of the field to the watershed outlet (8-digit HUC). Some columns do not add to totals because of rounding.
*See figure 77.

Table 47. Average annual nitrogen loads ***delivered to watershed outlets*** (8-digit HUCs***) from all sources*** in the Great Lakes Region, baseline conservation condition, by source

4-digit HUC group*	Basins within Great Lakes Region	All sources	Cultivated cropland*	Hayland	Pasture and grazing land	Urban: Nonpoint sources**	Urban: Point sources	Forest and other***
					Amount (1,000 pounds)			
I	Lake Superior Basin including St. Louis River	23,865	3,192	1,161	1,198	5,623	3,604	9,089
II	Western Lake Michigan Basin including Fox River	153,182	65,060	11,597	19,192	24,046	24,689	8,598
III	Eastern Lake Michigan Basin	199,007	90,972	13,733	16,662	41,633	14,560	21,446
IV	Lake Huron Basin including Saginaw River	125,781	66,541	6,566	6,503	22,795	11,961	11,415
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	283,998	132,863	7,109	10,957	37,377	89,636	6,057
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	144,236	59,769	14,212	16,729	14,065	20,370	19,091
	Regional total	930,069	418,397	54,377	71,241	145,539	164,820	75,696
					Percent of all sources			
I	Lake Superior Basin including St. Louis River	100	13	5	5	24	15	38
II	Western Lake Michigan Basin including Fox River	100	42	8	13	16	16	6
III	Eastern Lake Michigan Basin	100	46	7	8	21	7	11
IV	Lake Huron Basin including Saginaw River	100	53	5	5	18	10	9
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	100	47	3	4	13	32	2
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	100	41	10	12	10	14	13
	Regional total	100	45	6	8	16	18	8

* Includes land in long-term conserving cover, excludes horticulture.
** Includes construction sources and urban land runoff.
*** Includes forests (all types), wetlands, horticulture, and barren land.

Figure 85. Percentage by source of average annual nitrogen loads delivered to rivers and streams in the Great Lakes Region, baseline conservation condition

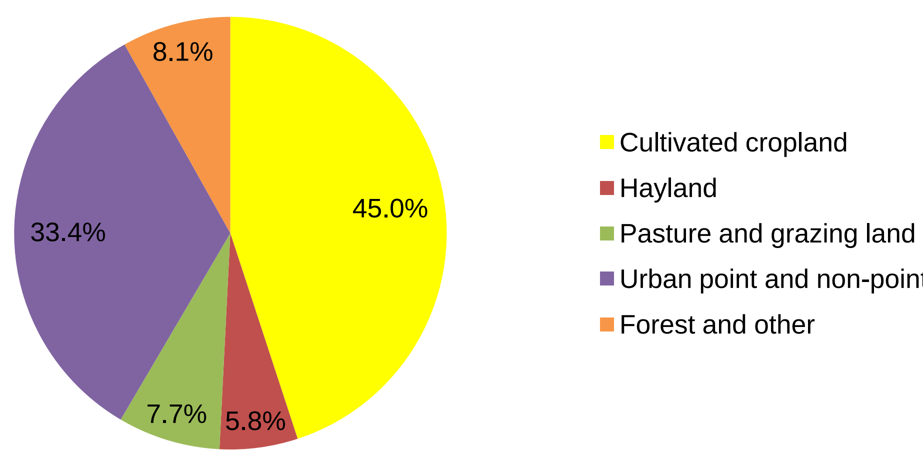


Table 48. Average annual ***instream nitrogen loads*** (all sources) delivered to the Great Lakes

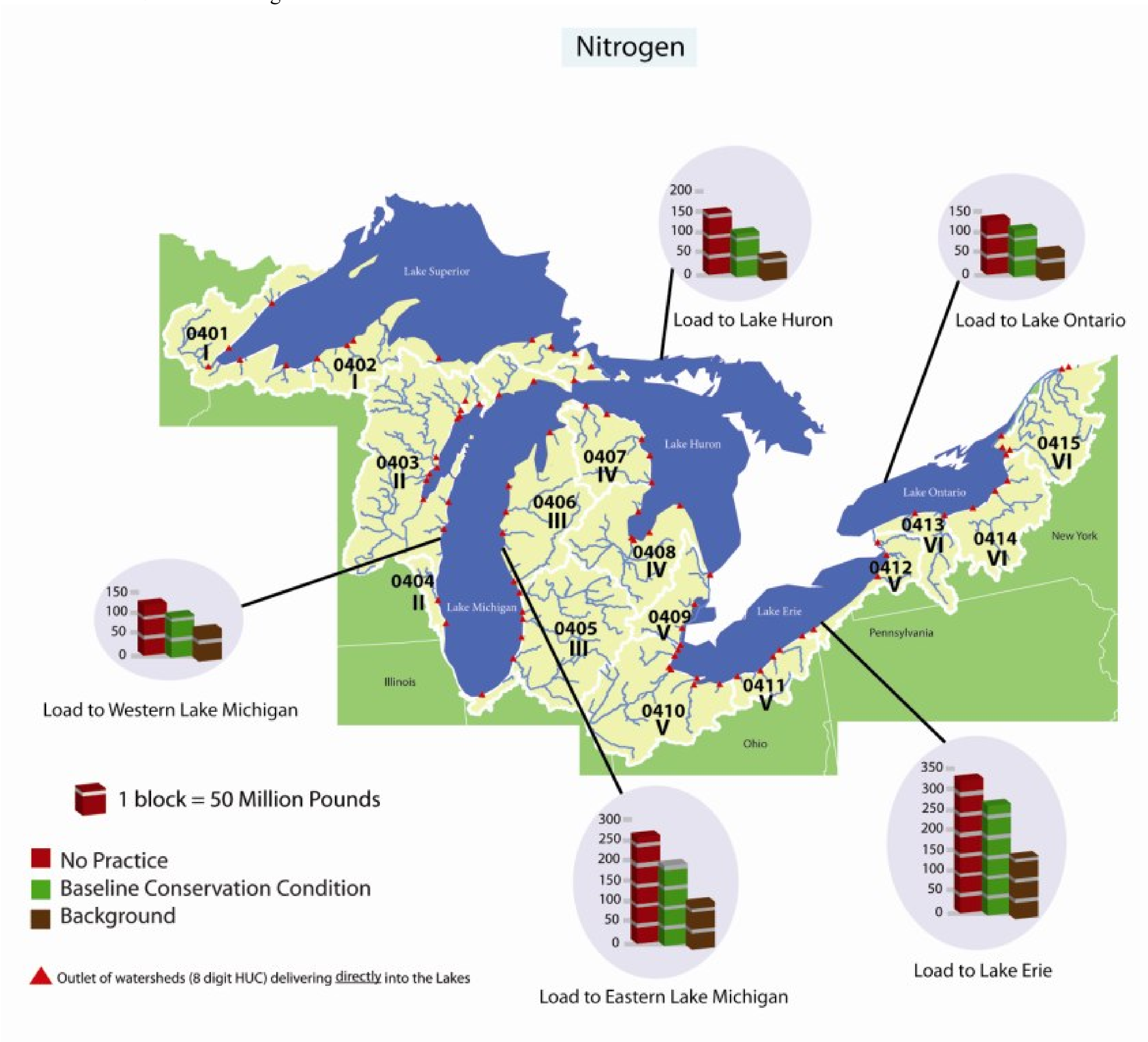
4-digit HUC group*	Basins within Great Lakes Region	Baseline conservation condition: Load from all sources (1,000 pounds)	Baseline conservation condition: Background sources** (1,000 pounds)	Baseline conservation condition: Percent of load attributed to cultivated cropland sources	No-practice scenario (1,000 pounds)	Reductions in loads due to conservation practices: Reduction (1,000 pounds)	Reductions in loads due to conservation practices: Percent
I	Lake Superior Basin including St. Louis River	21,530	18,770	13	24,020	2,490	10
II	Western Lake Michigan Basin including Fox River	106,700	70,900	34	136,800	30,100	22
III	Eastern Lake Michigan Basin	200,400	114,200	43	263,000	62,600	24
IV	Lake Huron Basin including Saginaw River	115,700	55,380	52	151,600	35,900	24
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	275,300	150,800	45	333,300	58,000	17
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	116,500	68,250	41	143,100	26,600	19
	Regional total	836,130	478,300	43	1,051,820	215,690	21

*See figure 77.

****** "Background sources" represent loadings that would be expected if no acres in the watershed were cultivated. These estimates were derived by running an additional scenario that simulated a grass and tree mix cover without any tillage or addition of nutrients or pesticides for all cultivated cropland acres in the watershed.

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

Figure 86. Estimates of average annual instream nitrogen loads for the baseline conservation condition compared to the no-practice scenario for the Great Lakes Region*



* Instream nitrogen loads delivered to the Great Lakes (all sources) are shown for each basin, corresponding to estimates presented in table 48.

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

Total Phosphorus

Baseline condition. Model simulation results show that about 35 million pounds of phosphorus are lost from farm fields (edge-of-field) per year within the Great Lakes Region (table 49) under conditions represented by the baseline conservation condition, which includes farming activities and conservation practices in use during the period 2003–06. Of this, about 22 million pounds are delivered into rivers and streams, on average (table 50).

The most phosphorus delivered to rivers and streams is in the Lake Erie basin (9.8 million pounds per year, 44 percent of the total) (table 50). On a per-acre basis, however, phosphorus delivery is highest in the Lake Ontario basin, averaging 5.2 pounds per cultivated cropland acre lost at the edge of the field and 3.0 pounds per acre delivered to rivers and streams (tables 49 and 50). Among the remaining basins, per-acre phosphorus loss ranged from 1.1 to 2.1 pounds lost at the edge of the field and 0.7 to 1.4 pounds delivered to rivers and streams (tables 49 and 50).

Phosphorus delivered to rivers and streams from cultivated cropland represents about 47 percent of the total phosphorus load delivered from all sources (table 51, fig. 87). This percentage ranges from 5 percent in the Lake Superior basin to 61 percent in the Lake Erie basin (table 51).

Urban sources (point sources and nonpoint sources) accounted for 34 percent of the total phosphorus load delivered from all sources to rivers and streams in the region. In all but the Lake Superior basin, phosphorus loads delivered to rivers and streams from cultivated cropland exceed phosphorus loads from urban runoff and point sources.

Instream loads—the amount of phosphorus delivered from all sources to the Lakes after accounting for instream deposition and transport processes—total about 37 million pounds per year, averaged over the 47 years of weather as simulated in the model (table 52). Of this, about 43 percent is attributed to cultivated cropland sources in the model simulation. The amount attributed to cultivated cropland was determined by subtracting the loads delivered to the Lakes in the "background" scenario (no cultivation) from the total load from all sources in the baseline conservation scenario (table 48).

Lake Erie receives the most phosphorus from all sources—14 million pounds per year, on average, with 57 percent attributable to cultivated cropland sources. Lake Michigan receives 9.4 million pounds per year, with 40 percent attributable to cultivated cropland sources. Lake Ontario receives 8.4 million pounds per year, with 34 percent attributable to cultivated cropland sources.

Effects of conservation practices. Conservation practices in use throughout the watershed have reduced phosphorus loads from farm fields. Model simulations indicate that conservation practices have reduced the delivery of phosphorus from fields to rivers and streams by about 36 percent (table 50), on average. Reductions due to conservation practices varied among the six basins, ranging from 26 percent for the Lake Ontario basin to 52 percent for the Eastern Lake Michigan basin.

Model simulations of instream loads indicate that conservation practices have reduced the delivery of phosphorus to the Lakes by about 20 percent overall (table 52). Without conservation practices, the total phosphorus delivered to the Lakes would be larger by 9.4 million pounds per year (table 52, figure 88). The largest percent reduction in loads delivered to the Lakes is in the Eastern Lake Michigan basin—36 percent.

Table 49. Average annual phosphorus loads ***delivered to edge of field*** (APEX model output) from cultivated cropland in the Great Lakes Region

4-digit HUC group*	Basins within Great Lakes Region	Baseline conservation condition: Amount (1,000 pounds)	Baseline conservation condition: Percent of basin total	Baseline conservation condition: Pounds delivered per cropland acre	No-practice Scenario (1,000 pounds)	Reductions in loads due to conservation practices: Reduction (1,000 pounds)	Reductions in loads due to conservation practices: Percent
I	Lake Superior Basin including St. Louis River	135	<1	1.09	288	153	53
II	Western Lake Michigan Basin including Fox River	5,966	17	1.91	11,480	5,512	48
III	Eastern Lake Michigan Basin	4,978	14	1.25	10,300	5,319	52
IV	Lake Huron Basin including Saginaw River	2,788	8	1.17	4,320	1,532	35
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	14,210	40	2.05	20,860	6,655	32
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	7,156	20	5.19	10,810	3,656	34
	Regional total	35,230	100	1.97	58,060	22,830	39

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Loads represent both cropped acres and land in long-term conserving cover. Some columns do not add to totals because of rounding.
*See figure 77.

Table 50. Average annual phosphorus loads ***delivered to watershed outlets*** (8-digit HUCs) ***from cultivated cropland*** in the Great Lakes Region

4-digit HUC group*	Basins within Great Lakes Region	Baseline conservation condition: Amount (1,000 pounds)	Baseline conservation condition: Percent of basin total	Baseline conservation condition: Pounds delivered per cropland acre	No-practice Scenario (1,000 pounds)	Reductions in loads due to conservation practices: Reduction (1,000 pounds)	Reductions in loads due to conservation practices: Percent
I	Lake Superior Basin including St. Louis River	85	<1	0.69	176	91	51
II	Western Lake Michigan Basin including Fox River	3,404	15	1.09	6,351	2,948	46
III	Eastern Lake Michigan Basin	3,109	14	0.78	6,489	3,381	52
IV	Lake Huron Basin including Saginaw River	1,928	9	0.81	2,946	1,019	35
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	9,800	44	1.42	13,340	3,544	27
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	4,165	19	3.02	5,659	1,495	26
	Regional total	22,490	100	1.25	34,960	12,480	36

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. The differences between loadings in this table and table 49 are due to the application of delivery ratios, which were used to simulate delivery of phosphorus from the edge of the field to the watershed outlet (8-digit HUC). Some columns do not add to totals because of rounding.
*See figure 77.

Table 51. Average annual phosphorus loads ***delivered to watershed outlets*** (8-digit HUCs***) from all sources*** in the Great Lakes Region, baseline conservation condition, by source

4-digit HUC group*	Basins within Great Lakes Region	All sources	Cultivated cropland*	Hayland	Pasture and grazing land	Urban: Nonpoint sources**	Urban: Point sources	Forest and other***
					Amount (1,000 pounds)			
I	Lake Superior Basin including St. Louis River	1,609	85	40	106	210	747	421
II	Western Lake Michigan Basin including Fox River	7,341	3,404	201	614	855	2,339	228
III	Eastern Lake Michigan Basin	6,116	3,109	180	630	733	1,122	343
IV	Lake Huron Basin including Saginaw River	4,511	1,928	132	374	515	1,275	287
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	16,008	9,800	394	866	1,760	2,800	388
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	12,195	4,165	1,291	1,807	466	3,532	935
	Regional total	47,780	22,490	2,238	4,397	4,238	11,815	2,602
					Percent of all sources			
I	Lake Superior Basin including St. Louis River	100	5	2	7	13	46	26
II	Western Lake Michigan Basin including Fox River	100	46	3	8	8	32	3
III	Eastern Lake Michigan Basin	100	51	3	10	12	18	6
IV	Lake Huron Basin including Saginaw River	100	43	3	8	11	28	6
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	100	61	2	5	11	17	2
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	100	34	11	15	4	29	8
	Regional total	100	47	5	9	9	25	5

* Includes land in long-term conserving cover, excludes horticulture.
** Includes construction sources and urban land runoff.
*** Includes forests (all types), wetlands, horticulture, and barren land.

Figure 87. Percentage by source of average annual phosphorus loads delivered to rivers and streams in the Great Lakes Region, baseline conservation condition

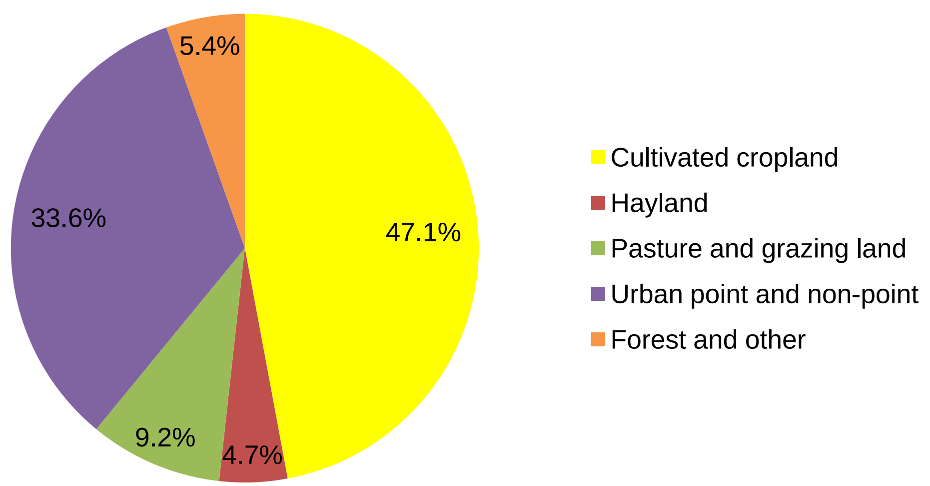


Table 52. Average annual ***instream phosphorus loads*** (all sources) delivered to the Great Lakes

4-digit HUC group*	Basins within Great Lakes Region	Baseline conservation condition: Load from all sources (1,000 pounds)	Baseline conservation condition: Background sources** (1,000 pounds)	Baseline conservation condition: Percent of load attributed to cultivated cropland sources	No-practice scenario (1,000 pounds)	Reductions in loads due to conservation practices: Reduction (1,000 pounds)	Reductions in loads due to conservation practices: Percent
I	Lake Superior Basin including St. Louis River	1,271	1,212	5	1,341	70	5
II	Western Lake Michigan Basin including Fox River	5,071	3,268	36	6,987	1,916	27
III	Eastern Lake Michigan Basin	4,448	2,422	46	6,976	2,528	36
IV	Lake Huron Basin including Saginaw River	3,818	2,359	38	4,711	893	19
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	13,770	5,969	57	16,760	2,990	18
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	8,374	5,541	34	9,334	960	10
	Regional total	36,752	20,771	43	46,109	9,357	20

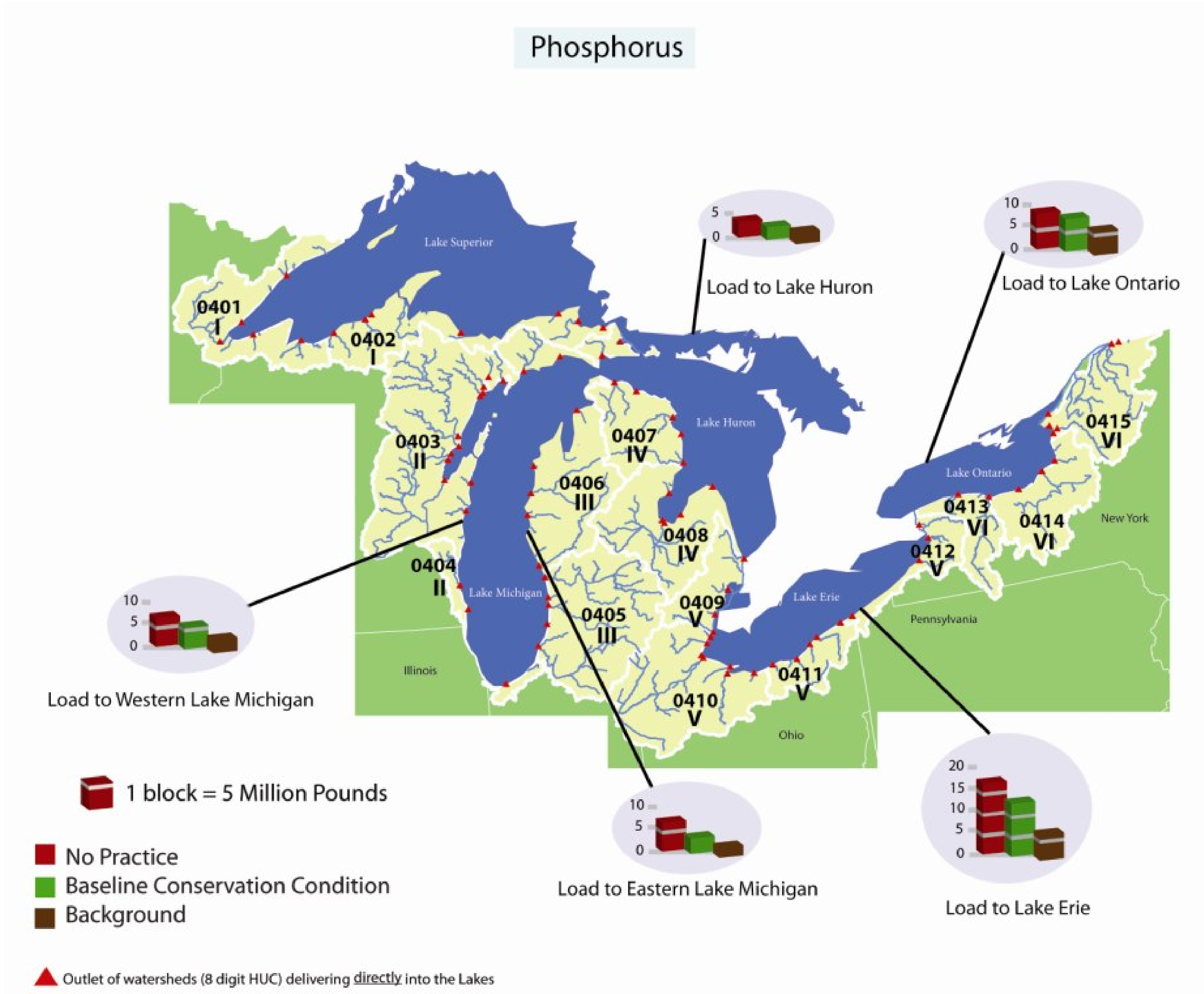
*See figure 77.

****** "Background sources" represent loadings that would be expected if no acres in the watershed were cultivated. These estimates were derived by running an additional scenario that simulated a grass and tree mix cover without any tillage or addition of nutrients or pesticides for all cultivated cropland acres in the watershed.

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

.

Figure 88. Estimates of average annual instream phosphorus loads for the baseline conservation condition compared to the no-practice scenario for the Great Lakes Region*



* Instream phosphorus loads delivered to the Great Lakes (all sources) are shown for each basin, corresponding to estimates presented in table 52.

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

Atrazine

Although the full suite of pesticides was modeled for edge-of-field losses, atrazine was the only pesticide for which in-stream loads were assessed because it was the dominant contributor to mass loss of pesticide residues from farm fields and the primary contributor to environmental risk from pesticides in the region. First registered in the United States in 1959, atrazine is used to control broadleaf and grassy weeds. Cultivated cropland (primarily corn acres) was the only source for atrazine in the model simulations.

Baseline condition. Model simulation results show that nearly 54,000 pounds of atrazine are lost from farm fields (edge-of-field) through pathways that result in delivery to streams and rivers within the Great Lakes Region (table 53). Of this, about 47,000 pounds are delivered into rivers and streams each year, on average, under conditions represented by the baseline conservation condition (table 54). About half of the atrazine delivered to rivers and streams from cultivated cropland is in the Lake Erie basin, and about one-third of the atrazine is in the Eastern Lake Michigan basin.

Instream loads—the amount of atrazine delivered to the Lakes after accounting for degradation and other instream transport processes—total about 40,000 pounds per year (table 55), including 18,500 pounds per year in the Lake Erie basin and 13,800 pounds per year in the Eastern Lake Michigan Basin. The remaining basins have relatively small atrazine loads.

Effects of conservation practices. Conservation practices—including Integrated Pest Management (IPM) techniques and practices—have reduced the delivery of atrazine from fields to rivers and streams by about 24 percent (table 54), on average. Reductions due to conservation practices varied among the six basins, ranging from 4 percent for the Lake Ontario basin to 38 percent for the Lake Huron basin. Percent reductions in the Eastern Lake Michigan basin and the Lake Erie basin were 27 and 23 percent, respectively.

Model simulations of instream loads indicate that conservation practices have reduced the delivery of atrazine to the Lakes by about 23 percent overall (table 55). Without conservation practices, the total atrazine delivered to the Lakes would be larger by 12,000 pounds per year (table 55, figure 89). The largest percent reduction in loads delivered to the Lakes is in the Lake Huron basin—39 percent.

Table 53. Average annual atrazine source loads ***delivered to edge of field*** (APEX model output) from cultivated cropland for the Great Lakes Region

4-digit HUC group*	Basins within Great Lakes Region	Baseline conservation condition: Amount (1,000 pounds)	Baseline conservation condition: Percent of basin total	Baseline conservation condition: Pounds delivered per cropland acre	No-practice Scenario (1,000 pounds)	Reductions in loads due to conservation practices: Reduction (1,000 pounds)	Reductions in loads due to conservation practices: Percent
I	Lake Superior Basin including St. Louis River	0.21	0.4	0.0017	0.31	0.10	32
II	Western Lake Michigan Basin including Fox River	4.27	8	0.0014	5.60	1.34	24
III	Eastern Lake Michigan Basin	16.53	31	0.0041	21.72	5.19	24
IV	Lake Huron Basin including Saginaw River	2.06	4	0.0009	3.18	1.12	35
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	24.70	46	0.0036	30.61	5.91	19
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	6.11	11	0.0044	6.39	0.28	4
	Regional total	53.88	100	0.0030	67.81	13.93	21

Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Loads represent both cropped acres and land in long-term conserving cover. Some columns do not add to totals because of rounding.
*See figure 77.

Table 54. Average annual atrazine source loads ***delivered to watershed outlets*** (8-digit HUCs) from cultivated cropland for the Great Lakes Region

4-digit HUC group*	Basins within Great Lakes Region	Baseline conservation condition: Amount (1,000 pounds)	Baseline conservation condition: Percent of basin total	Baseline conservation condition: Pounds delivered per cropland acre	No-practice Scenario (1,000 pounds)	Reductions in loads due to conservation practices: Reduction (1,000 pounds)	Reductions in loads due to conservation practices: Percent
I	Lake Superior Basin including St. Louis River	0.18	0.4	0.0014	0.26	0.08	33
II	Western Lake Michigan Basin including Fox River	3.78	8	0.0012	5.02	1.24	25
III	Eastern Lake Michigan Basin	14.74	32	0.0037	20.09	5.35	27
IV	Lake Huron Basin including Saginaw River	1.72	4	0.0007	2.79	1.07	38
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	21.73	47	0.0031	28.21	6.49	23
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	4.53	10	0.0033	4.74	0.21	4
	Regional total	46.67	100	0.0026	61.12	14.45	24

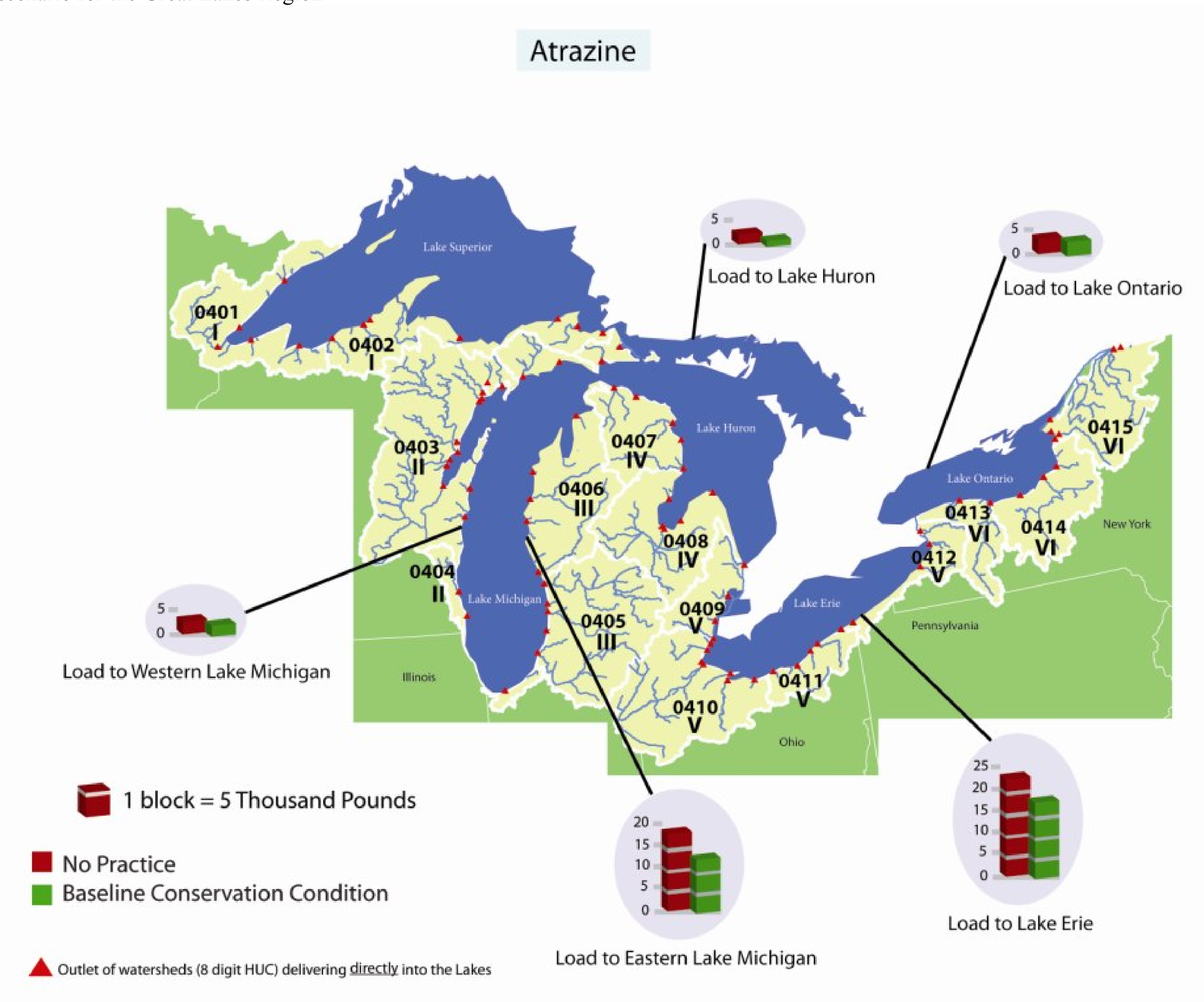
Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. The differences between loadings in this table and table 53 are due to the application of delivery ratios, which were used to simulate delivery of atrazine from the edge of the field to the watershed outlet (8-digit HUC). Some columns do not add to totals because of rounding.
*See figure 77.

Table 55. Average annual ***instream atrazine loads*** delivered to the Great Lakes

4-digit HUC group*	Basins within Great Lakes Region	Baseline conservation condition (1,000 pounds)	No-practice scenario (1,000 pounds)	Reductions in loads due to conservation practices: Reduction (1,000 pounds)	Reductions in loads due to conservation practices: Percent
I	Lake Superior Basin including St. Louis River	0.15	0.23	0.07	33
II	Western Lake Michigan Basin including Fox River	2.42	3.02	0.60	20
III	Eastern Lake Michigan Basin	13.80	18.82	5.01	27
IV	Lake Huron Basin including Saginaw River	1.54	2.53	0.99	39
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	18.51	23.81	5.30	22
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	3.81	3.89	0.08	2
	Regional total	40.23	52	12.05	23

*See figure 77.
Note: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Some columns do not add to totals because of rounding.

Figure 89. Estimates of average annual instream atrazine loads for the baseline conservation condition compared to the no-practice scenario for the Great Lakes Region*



* Instream atrazine loads delivered to the Great Lakes (all sources) are shown for each basin, corresponding to estimates presented in table 55.

Assessment of Potential Water Quality Gains from Further Conservation Treatment

The field-level model results for the scenarios with additional erosion control practices and nutrient management (chapter 6) were used with the HUMUS/SWAT model to determine the potential for further reductions in loads delivered from cultivated cropland to rivers and streams within the watershed and total loads delivered to the Lakes (instream loads) with additional conservation treatment.

Percent reductions relative to the baseline conservation condition were estimated for each of two scenarios—

1. Treatment of the 2.84 million critical under-treated acres, which have a high need for additional treatment for one or more resource concern (19 percent of cropped acres in the region), and
2. Treatment of the 7.9 million acres with a high or moderate need for additional treatment for one or more resource concern, including the 2.84 million critical under-treated acres (53 percent of cropped acres in the region).

Acres not receiving treatment in the simulation retained baseline values. Thus, the distribution of under-treated acres within the region influences the extent to which individual subregions benefit from additional treatment, since additional treatment was simulated only for the under-treated acres. The distribution of under-treated acres within the Great Lakes Region is shown in chapter 5, table 31.

About half of the cropped acres in the Western and Eastern Lake Michigan basins and the Lake Huron basin are under-treated, with 24 to 26 percent critically under-treated. About half of cropped acres in the Lake Erie basin are under-treated as well, but only 8 percent are critically under-treated. In contrast, 71 percent of cropped acres in the Lake Ontario basin are under-treated, with 32 percent critically under-treated for one or more resource concerns. (The CEAP sample was too small in the Lake Superior basin to estimate under-treated acres; consequently, potential gains from additional treatment of those acres are not reported.)

The effects of additional treatment on edge-of-field losses for critical under-treated acres and all undertreated acres are shown in tables 56, 59, 62, and 65. These estimates differ somewhat from edge-of-field estimates reported in chapter 6 because land in long-term conserving cover is included.

Model simulations showed that if the 2.84 million critical under-treated acres were fully treated with the appropriate soil erosion control and nutrient management practices, loads from cultivated cropland delivered to rivers and streams in the Great Lakes region would be reduced by, relative to the baseline conservation condition (tables 57, 60, 63, and 66)—

- 25 percent for sediment,
- 18 percent for nitrogen,
- 11 percent for phosphorus, and
- 4 percent for atrazine.

Percent reductions were highest for the Lake Ontario basin, primarily because a higher proportion of cropped acres in this basin had additional conservation treatment in the model simulation.

Model simulations further showed that if **all** of the under-treated acres (an additional 5.04 million acres) were fully treated with the appropriate soil erosion control and nutrient management practices, loads from cultivated cropland delivered to rivers and streams in the watershed would be reduced, relative to the baseline conservation condition (tables 57, 60, 63, and 66)—

- 58 percent for sediment,
- 37 percent for nitrogen,
- 33 percent for phosphorus, and
- 12 percent for atrazine.

These reductions in loads delivered to rivers and streams from cultivated cropland would reduce the total loads delivered to the Lakes. If the critical under-treated acres (2.84 million acres) were fully treated with the appropriate soil erosion control and nutrient management practices, total loads delivered to the Lakes from all sources would be reduced, relative to the baseline conservation condition (tables 58, 61, 64, 67 and figs. 90 through 93)—

- 4 percent for sediment,
- 8 percent for nitrogen,
- 5 percent for phosphorus, and
- 4 percent for atrazine.

If **all** the under-treated acres (5.04 million additional acres) were fully treated with the appropriate soil erosion control and nutrient management practices, total loads delivered to the Lakes from all sources would be reduced, relative to the baseline conservation condition (tables 58, 61, 64, 67 and figs. 90 through 93)—

- 9 percent for sediment,
- 16 percent for nitrogen,
- 15 percent for phosphorus, and
- 11 percent for atrazine.

Reductions in loads delivered to the Lakes vary from basin to basin depending on the extent of other sources of contaminants and the number of under-treated acres in each basin.

As shown in table 58 and figure 90, sediment loads delivered to the lake in each basin would be very close to “background” levels after additional conservation treatment of the under-treated acres, indicating that contributions from cultivated cropland would be nearly negligible. The background scenario represents loads that would be expected if no acres in the watershed were cultivated. Background loads total 7.56 million tons (table 58) for all basins compared to 8.14 million tons delivered from all sources after treating all under-treated acres with appropriate conservation treatment, leaving only about 0.57 million tons originating from cultivated cropland.

Using similar calculations, if all under-treated acres (53 percent of cropped acres) were fully treated, loads originating from cultivated cropland delivered to the Lakes would be reduced to about 227 million pounds for nitrogen and 10 million pounds for phosphorus (tables 61 and 64). To reduce loads further would require additional conservation treatment of the remaining 7 million cropped acres with a low level of conservation treatment need, which would have a low per-acre benefit as shown in table 37.

Table 56. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual **sediment source loads *delivered to edge of field*** (APEX model output) from cultivated cropland for the Great Lakes Region

		Baseline conservation condition	Treatment of 2.84 million critical under-treated acres		Treatment of all 7.9 million under-treated acres	
4-digit HUC group*	Basins within Great Lakes Region	Average annual load (1,000 tons)	Average annual load (1,000 tons)	Percent reduction	Average annual load (1,000 tons)	Percent reduction
II	Western Lake Michigan Basin including Fox River	2,575	1,810	30	1,012	61
III	Eastern Lake Michigan Basin	1,787	1,261	29	641	64
IV	Lake Huron Basin including Saginaw River	600	518	14	279	54
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	3,404	2,679	21	1,481	56
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	2,372	1,652	30	951	60
	Regional total	10,800	7,972	26	4,396	59

Notes: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Loads represent both cropped acres and land in long-term conserving cover. Some columns do not add to totals because of rounding. Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment. CEAP sample size in Lake Superior was too small to report results of additional conservation treatment.
*See figure 77.

Table 57. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual **sediment source loads *delivered to watershed outlets*** (8-digit HUCs) from cultivated cropland for the Great Lakes Region

		Baseline conservation condition	Treatment of 2.84 million critical under-treated acres		Treatment of all 7.9 million under-treated acres	
4-digit HUC group*	Basins within Great Lakes Region	Average annual load (1,000 tons)	Average annual load (1,000 tons)	Percent reduction	Average annual load (1,000 tons)	Percent reduction
II	Western Lake Michigan Basin including Fox River	971	700	28	394	59
III	Eastern Lake Michigan Basin	605	441	27	229	62
IV	Lake Huron Basin including Saginaw River	241	208	14	115	52
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	1,327	1,071	19	613	54
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	922	616	33	342	63
	Regional total	4,087	3,054	25	1,703	58

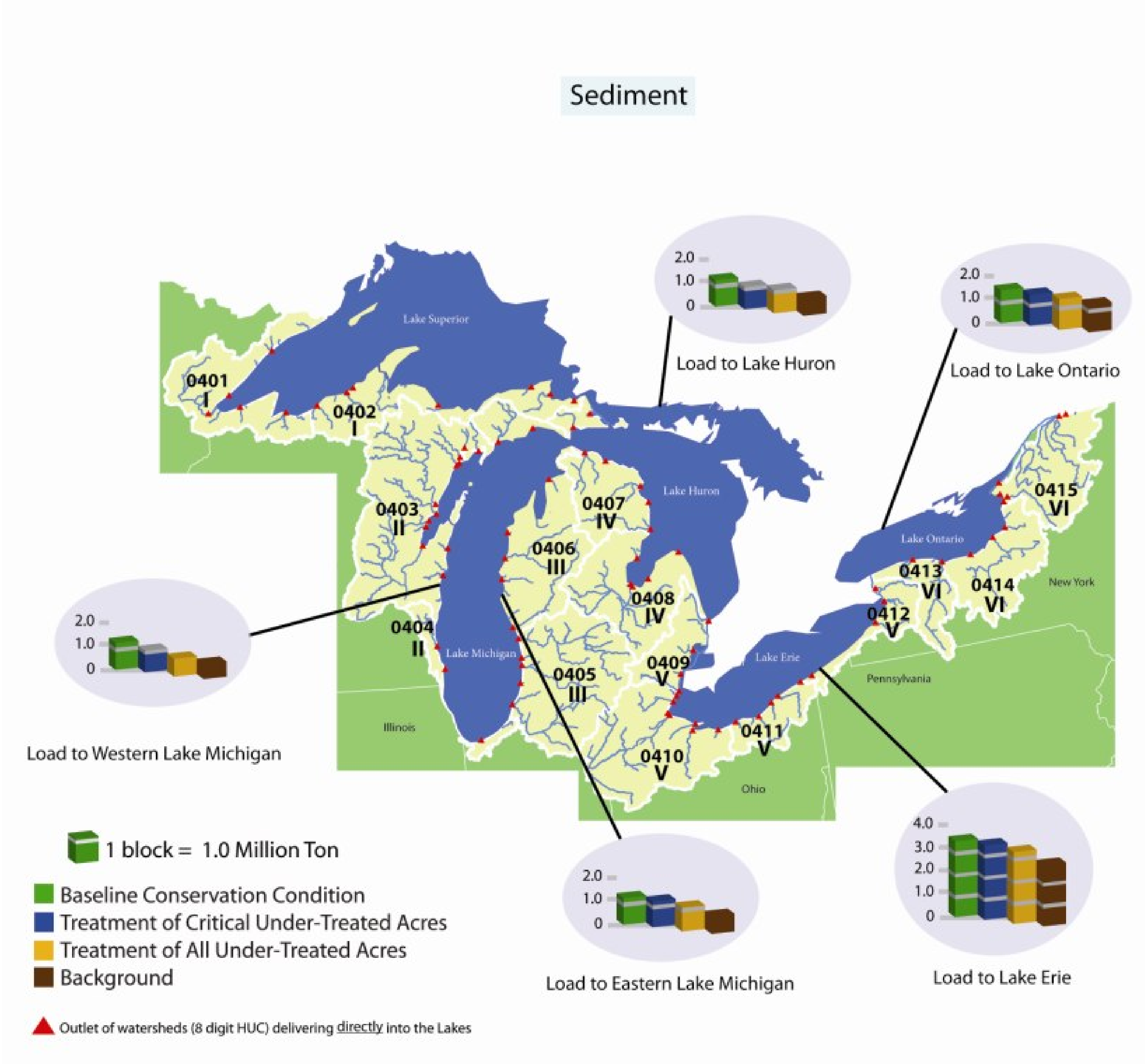
Notes: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. The differences between loadings in this table and table 56 are due to the application of delivery ratios, which were used to simulate delivery of sediment from the edge of the field to the watershed outlet (8-digit HUC). Some columns do not add to totals because of rounding. Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment. CEAP sample size in Lake Superior was too small to report results of additional conservation treatment.
*See figure 77.

Table 58. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual ***instream sediment loads*** from all sources delivered to the Great Lakes

		Baseline conservation condition		Treatment of 2.84 million critical under-treated acres		Treatment of all 7.9 million under-treated acres	
4-digit HUC group*	Basins within Great Lakes Region	Average annual load from all sources (1,000 tons)	Average annual load from background sources** (1,000 tons)	Average annual load (1,000 tons)	Percent reduction	Average annual load (1,000 tons)	Percent reduction
II	Western Lake Michigan Basin including Fox River	1,115	799	1,040	7	931	16
III	Eastern Lake Michigan Basin	1,127	938	1,084	4	1,015	10
IV	Lake Huron Basin including Saginaw River	1,053	981	1,037	2	1,001	5
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	3,374	2,943	3,302	2	3,145	7
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	1,525	1,189	1,405	8	1,322	13
	Regional total	8,922	7,564	8,594	4	8,136	9

*See figure 77.
** "Background sources" represent loads that would be expected if no acres in the watershed were cultivated. These estimates were derived by running an additional scenario that simulated a grass and tree mix cover without any tillage or addition of nutrients or pesticides for all cultivated cropland acres in the watershed. "Background" loads include loads from all other land uses—hayland, pastureland, rangeland, horticulture, forestland, and urban land—as well as point sources.
Notes: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Some columns do not add to totals because of rounding. Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment. CEAP sample size in Lake Superior was too small to report results of additional conservation treatment.

Figure 90. Estimates of average annual instream sediment loads* for the baseline conservation condition compared to two scenarios simulating additional erosion control and nutrient management practices for the Great Lakes Region



* Instream sediment loads delivered to the Great Lakes (all sources) are shown for each basin, corresponding to estimates presented in table 58.

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

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

Table 59. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual **nitrogen source loads *delivered to edge of field*** (APEX model output) from cultivated cropland for the Great Lakes Region

		Baseline conservation condition	Treatment of 2.84 million critical under-treated acres		Treatment of all 7.9 million under-treated acres	
4-digit HUC group*	Basins within Great Lakes Region	Average annual load (1,000 pounds)	Average annual load (1,000 pounds)	Percent reduction	Average annual load (1,000 pounds)	Percent reduction
II	Western Lake Michigan Basin including Fox River	74,650	60,340	19	43,810	41
III	Eastern Lake Michigan Basin	99,110	78,050	21	65,710	34
IV	Lake Huron Basin including Saginaw River	69,100	53,930	22	42,880	38
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	148,700	136,900	8	101,100	32
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	68,180	45,040	34	32,120	53
	Regional total	463,100	376,100	19	287,400	38

Notes: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Loads represent both cropped acres and land in long-term conserving cover. Some columns do not add to totals because of rounding. Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment. CEAP sample size in Lake Superior was too small to report results of additional conservation treatment.
*See figure 77.

Table 60. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual **nitrogen source loads *delivered to watershed outlets*** (8-digit HUCs) from cultivated cropland for the Great Lakes Region

		Baseline conservation condition	Treatment of 2.84 million critical under-treated acres		Treatment of all 7.9 million under-treated acres	
4-digit HUC group*	Basins within Great Lakes Region	Average annual load (1,000 pounds)	Average annual load (1,000 pounds)	Percent reduction	Average annual load (1,000 pounds)	Percent reduction
II	Western Lake Michigan Basin including Fox River	65,050	53,040	18	39,220	40
III	Eastern Lake Michigan Basin	90,960	71,840	21	61,840	32
IV	Lake Huron Basin including Saginaw River	66,530	51,460	23	41,490	38
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	132,800	123,000	7	91,970	31
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	59,760	40,070	33	28,860	52
	Regional total	418,300	341,100	18	265,000	37

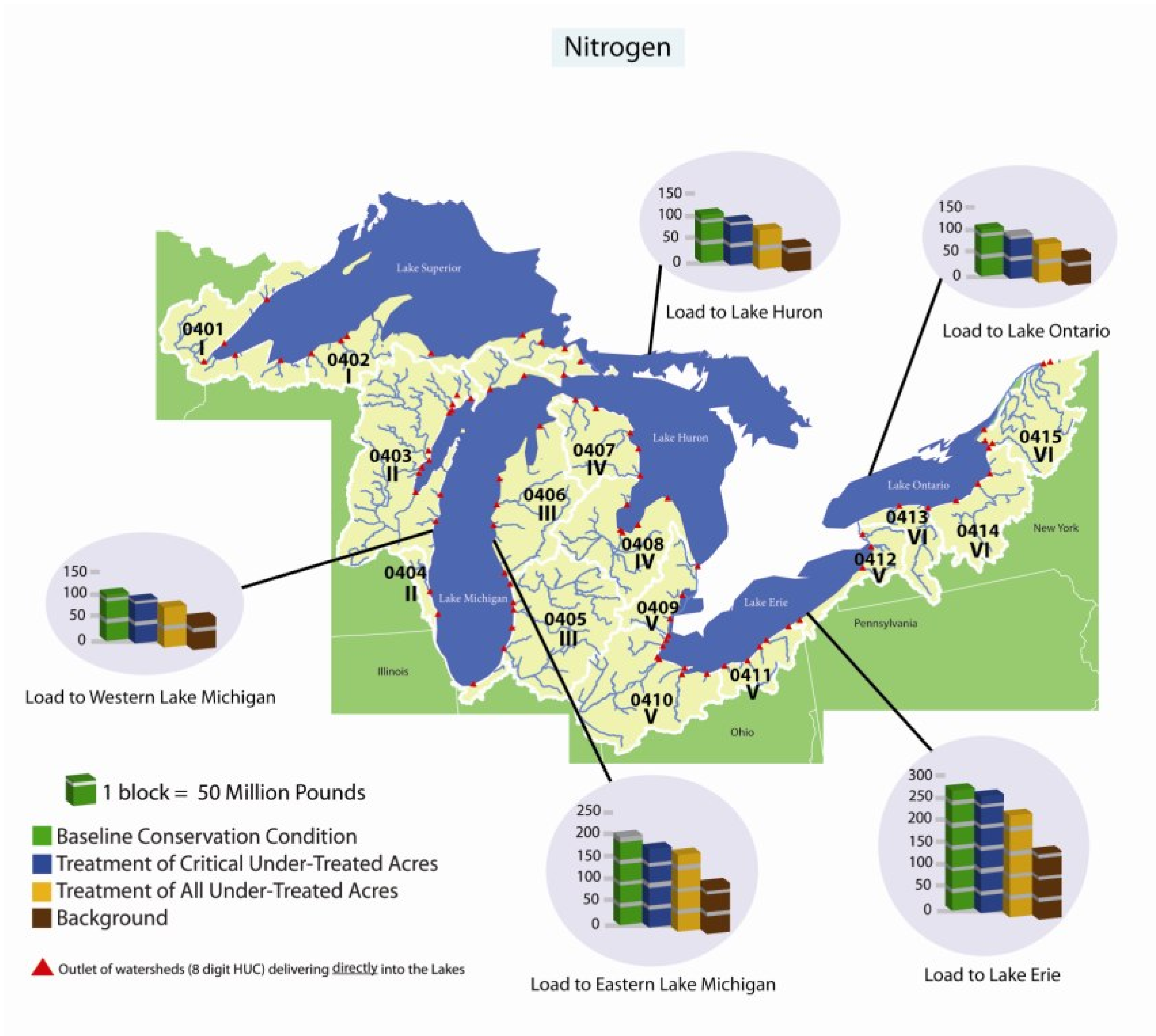
Notes: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. The differences between loadings in this table and table 59 are due to the application of delivery ratios, which were used to simulate delivery of nitrogen from the edge of the field to the watershed outlet (8-digit HUC). Some columns do not add to totals because of rounding. Note: Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment. CEAP sample size in Lake Superior was too small to report results of additional conservation treatment.
*See figure 77.

Table 61. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual ***instream nitrogen loads*** from all sources delivered to the Great Lakes

		Baseline conservation condition		Treatment of 2.84 million critical under-treated acres		Treatment of all 7.9 million under-treated acres	
4-digit HUC group*	Basins within Great Lakes Region	Average annual load from all sources (1,000 pounds)	Average annual load from background sources** (1,000 pounds)	Average annual load (1,000 pounds)	Percent reduction	Average annual load (1,000 pounds)	Percent reduction
II	Western Lake Michigan Basin including Fox River	106,700	70,900	101,300	5	94,210	12
III	Eastern Lake Michigan Basin	200,400	114,200	180,900	10	170,700	15
IV	Lake Huron Basin including Saginaw River	115,700	55,380	101,800	12	92,150	20
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	275,300	150,800	265,500	4	236,800	14
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	116,500	68,250	100,400	14	91,130	22
	Regional total	836,130	478,300	770,130	8	705,190	16

*See figure 77.
** “Background sources” represent loads that would be expected if no acres in the watershed were cultivated.
Notes: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Some columns do not add to totals because of rounding. Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment. CEAP sample size in Lake Superior was too small to report results of additional conservation treatment.

Figure 91. Estimates of average annual instream nitrogen loads* for the baseline conservation condition compared to two scenarios simulating additional erosion control and nutrient management practices for the Great Lakes Region



* Instream nitrogen loads delivered to the Great Lakes (all sources) are shown for each basin, corresponding to estimates presented in table 61.

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

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

Table 62. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual **phosphorus source loads *delivered to edge of field*** (APEX model output) from cultivated cropland for the Great Lakes Region

		Baseline conservation condition	Treatment of 2.84 million critical under-treated acres		Treatment of all 7.9 million under-treated acres	
4-digit HUC group*	Basins within Great Lakes Region	Average annual load (1,000 pounds)	Average annual load (1,000 pounds)	Percent reduction	Average annual load (1,000 pounds)	Percent reduction
II	Western Lake Michigan Basin including Fox River	5,966	5,192	13	3,534	41
III	Eastern Lake Michigan Basin	4,978	4,085	18	3,363	32
IV	Lake Huron Basin including Saginaw River	2,788	2,523	10	1,733	38
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	14,210	13,330	6	9,276	35
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	7,156	4,983	30	3,566	50
	Regional total	35,230	30,200	14	21,550	39

Notes: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Loads represent both cropped acres and land in long-term conserving cover. Some columns do not add to totals because of rounding. Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment. CEAP sample size in Lake Superior was too small to report results of additional conservation treatment.

*See figure 77.

Table 63. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual **phosphorus source loads *delivered to watershed outlets*** (8-digit HUCs) from cultivated cropland for the Great Lakes Region

		Baseline conservation condition	Treatment of 2.84 million critical under-treated acres		Treatment of all 7.9 million under-treated acres	
4-digit HUC group*	Basins within Great Lakes Region	Average annual load (1,000 pounds)	Average annual load (1,000 pounds)	Percent reduction	Average annual load (1,000 pounds)	Percent reduction
II	Western Lake Michigan Basin including Fox River	3,403	3,106	9	2,325	32
III	Eastern Lake Michigan Basin	3,108	2,665	14	2,347	24
IV	Lake Huron Basin including Saginaw River	1,927	1,735	10	1,267	34
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	9,798	9,383	4	6,645	32
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	4,164	3,149	24	2,408	42
	Regional total	22,490	20,090	11	15,040	33

Notes: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. The differences between loadings in this table and table 62 are due to the application of delivery ratios, which were used to simulate delivery of phosphorus from the edge of the field to the watershed outlet (8-digit HUC). Some columns do not add to totals because of rounding. Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment. CEAP sample size in Lake Superior was too small to report results of additional conservation treatment.

*See figure 77.

Table 64. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual ***instream phosphorus loads*** from all sources delivered to the Great Lakes

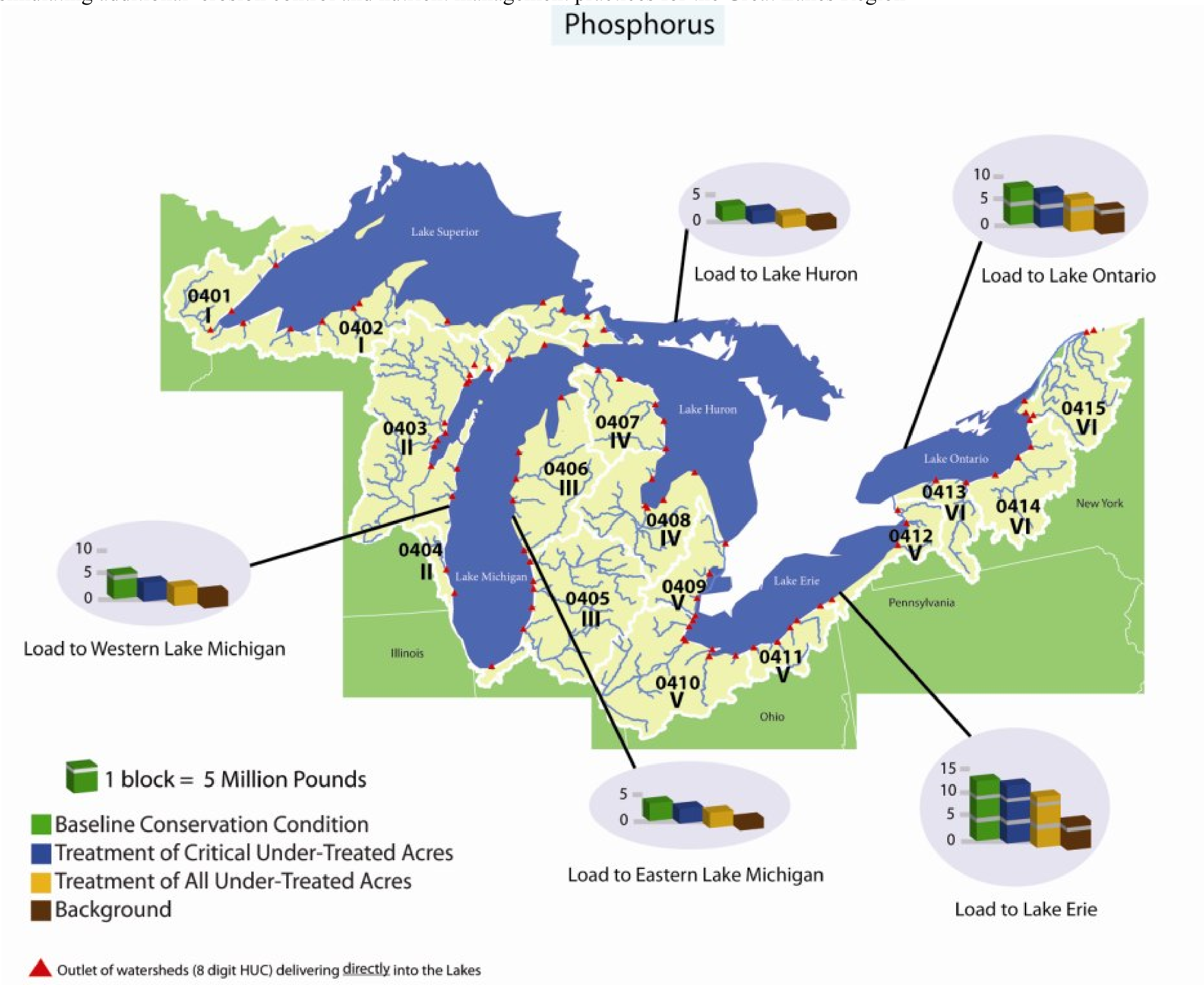
		Baseline conservation condition		Treatment of 2.84 million critical under-treated acres		Treatment of all 7.9 million under-treated acres	
4-digit HUC group*	Basins within Great Lakes Region	Average annual load from all sources (1,000 pounds)	Average annual load from background sources** (1,000 pounds)	Average annual load (1,000 pounds)	Percent reduction	Average annual load (1,000 pounds)	Percent reduction
II	Western Lake Michigan Basin including Fox River	5,071	3,268	4,895	3	4,535	11
III	Eastern Lake Michigan Basin	4,448	2,422	4,126	7	3,918	12
IV	Lake Huron Basin including Saginaw River	3,818	2,359	3,651	4	3,297	14
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	13,770	5,969	13,410	3	11,080	20
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	8,374	5,541	7,655	9	7,147	15
	Regional total	36,752	20,771	34,982	5	31,221	15

*See figure 77.

** "Background sources" represent loads that would be expected if no acres in the watershed were cultivated..

Notes: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Some columns do not add to totals because of rounding. Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment. CEAP sample size in Lake Superior was too small to report results of additional conservation treatment.

Figure 92. Estimates of average annual instream phosphorus loads* for the baseline conservation condition compared to two scenarios simulating additional erosion control and nutrient management practices for the Great Lakes Region



* Instream phosphorus loads delivered to the Great Lakes (all sources) are shown for each basin, corresponding to estimates presented in table 64.

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

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

Table 65. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual **atrazine source loads *delivered to edge of field*** (APEX model output) from cultivated cropland for the Great Lakes Region

		Baseline conservation condition	Treatment of 2.84 million critical under-treated acres		Treatment of all 7.9 million under-treated acres	
4-digit HUC group*	Basins within Great Lakes Region	Average annual load (1,000 pounds)	Average annual load (1,000 pounds)	Percent reduction	Average annual load (1,000 pounds)	Percent reduction
II	Western Lake Michigan Basin including Fox River	4.27	4.04	5	3.67	14
III	Eastern Lake Michigan Basin	16.53	15.45	7	14.67	11
IV	Lake Huron Basin including Saginaw River	2.06	1.97	5	1.80	13
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	24.70	23.83	4	21.04	15
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	6.11	5.62	8	5.40	12
	Regional total	53.88	51.10	5	46.78	13

Notes: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Loads represent both cropped acres and land in long-term conserving cover. Some columns do not add to totals because of rounding. Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment. CEAP sample size in Lake Superior was too small to report results of additional conservation treatment.
*See figure 77.

Table 66. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual **atrazine source loads *delivered to watershed outlets*** (8-digit HUCs) from cultivated cropland for the Great Lakes Region

		Baseline conservation condition	Treatment of 2.84 million critical under-treated acres		Treatment of all 7.9 million under-treated acres	
4-digit HUC group*	Basins within Great Lakes Region	Average annual load (1,000 pounds)	Average annual load (1,000 pounds)	Percent reduction	Average annual load (1,000 pounds)	Percent reduction
II	Western Lake Michigan Basin including Fox River	3.78	3.61	5	3.33	12
III	Eastern Lake Michigan Basin	14.74	13.95	5	13.42	9
IV	Lake Huron Basin including Saginaw River	1.72	1.64	4	1.49	13
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	21.73	21.08	3	18.77	14
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	4.53	4.24	6	4.11	9
	Regional total	46.67	44.68	4	41.28	12

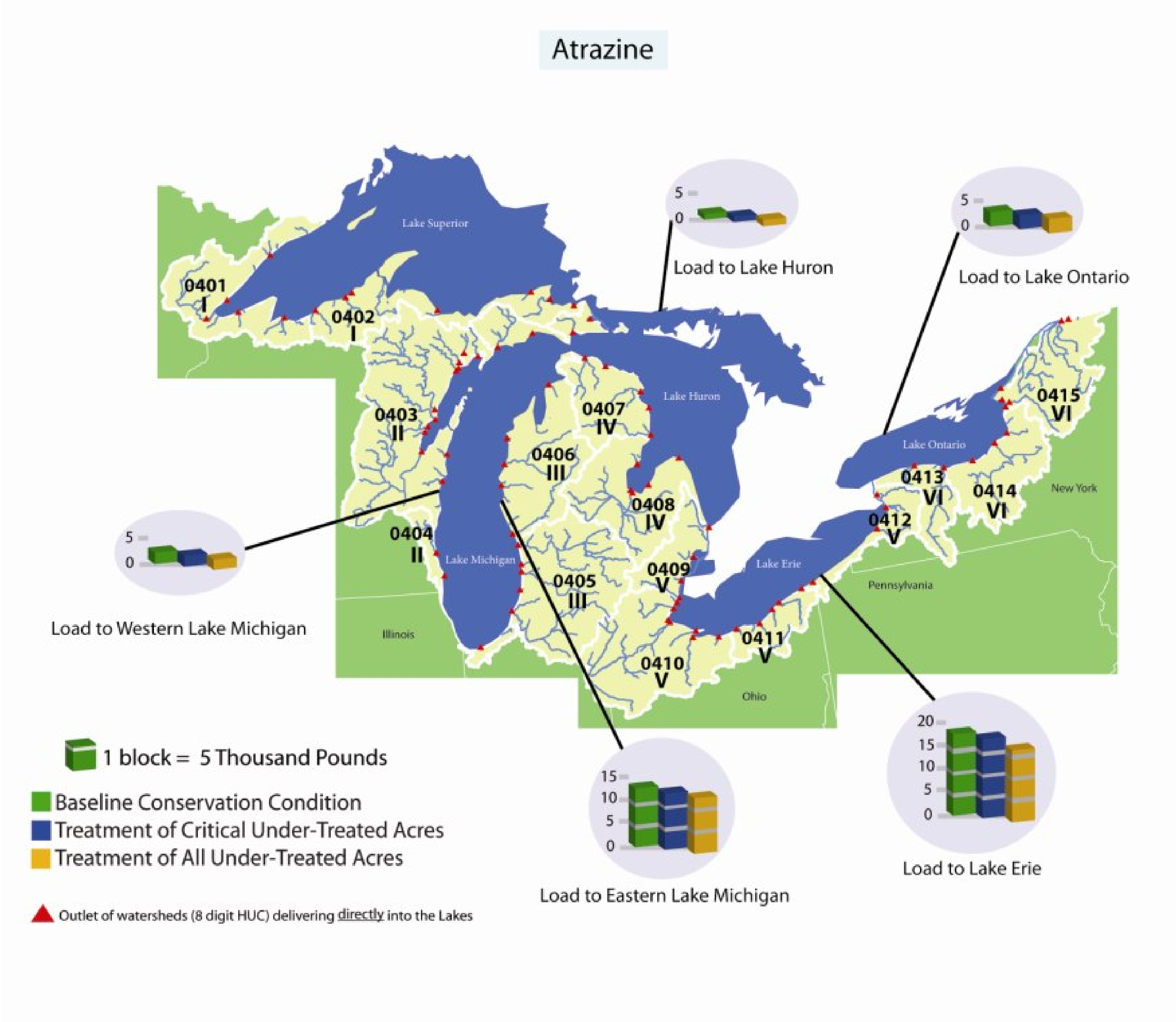
Notes: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. The differences between loadings in this table and table 65 are due to the application of delivery ratios, which were used to simulate delivery of atrazine from the edge of the field to the watershed outlet (8-digit HUC). Some columns do not add to totals because of rounding. Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment. CEAP sample size in Lake Superior was too small to report results of additional conservation treatment.
*See figure 77.

Table 67. Effects of additional conservation treatment with erosion control practices *and* nutrient management practices on average annual ***instream atrazine loads*** delivered to the Great Lakes

		Baseline conservation condition	Treatment of 2.84 million critical under-treated acres		Treatment of all 7.9 million under-treated acres	
4-digit HUC group*	Basins within Great Lakes Region	Average annual load from all sources (1,000 tons)	Average annual load (1,000 tons)	Percent reduction	Average annual load (1,000 tons)	Percent reduction
II	Western Lake Michigan Basin including Fox River	2.42	2.34	3	2.17	10
III	Eastern Lake Michigan Basin	13.80	13.12	5	12.67	8
IV	Lake Huron Basin including Saginaw River	1.54	1.47	4	1.34	13
V	Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	18.51	17.97	3	16.11	13
VI	Lake Ontario Basin including Oswego-St. Lawrence Rivers	3.81	3.62	5	3.55	7
	Regional total	40.23	38.66	4	35.98	11

*See figure 77.
Notes: Percent reductions were calculated prior to rounding the values for reporting in the table and the associated text. Some columns do not add to totals because of rounding. Critical under-treated acres have a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment. CEAP sample size in Lake Superior was too small to report results of additional conservation treatment.

Figure 93. Estimates of average annual instream atrazine loads* for the baseline conservation condition compared to two scenarios simulating additional erosion control and nutrient management practices for the Great Lakes Region



* Instream atrazine loads delivered to the Great Lakes (all sources) are shown for each basin, corresponding to estimates presented in table 67."

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

Chapter 8
Summary of Findings

Field Level Assessment

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 Great Lakes region closely reflects this history of Federal conservation programs and technical assistance. An assessment of the extent of conservation practice use, 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 26 percent of cropped acres. On the 17 percent of the acres designated as highly erodible land, structural practices designed to control water erosion are in use on 37 percent of those acres.
- Reduced tillage is common in the region; 82 percent of the cropped acres meet criteria for either no-till (32 percent) or mulch till (50 percent). All but 9 percent of the acres had evidence of some kind of reduced tillage on at least one crop.
- About 46 percent of cropped acres are gaining soil organic carbon. An additional 25 percent of cropped acres are considered to be “maintaining” soil organic carbon (average annual loss less than 100 pounds per acre). Overall, 71 percent of cropped acres are maintaining or enhancing soil organic carbon.
- Producers use either residue and tillage management practices or structural practices, or both, on 94 percent of the acres.
- While most acres have evidence of some nitrogen or phosphorus management, the majority of the acres in the region lack consistent use of appropriate rates, timing, *and* method of application on each crop in every year of production, including nearly all of the acres receiving manure.
    - Appropriate timing of nitrogen applications is in use on about 69 percent of the acres for all crops in the rotation.
    - About 40 percent of cropped acres meet criteria for appropriate nitrogen application rates for all crops in the rotation.
    - Appropriate nitrogen application rates, timing of application, and application method for all crops during every year of production, however, are in use on only about 18 percent of cropped acres.
    - Good phosphorus management practices (appropriate rate, timing, and method) are in use on 29 percent of the acres on all crops during every year of production.
    - Only about 12 percent of cropped acres meet full nutrient management criteria for *both* phosphorus and nitrogen management, including acres not receiving nutrient applications.
- During the 2003–06 period of data collection, cover crops were used on about 1 percent of the acres in the region.
- An Integrated Pest Management (IPM) indicator showed that only about 6 percent of the acres were being managed at a relatively high level of IPM.
- Land in long-term conserving cover, as represented by enrollment in the CRP General Signup, consists of about 593,000 acres in the region, of which 40 percent is highly erodible land.

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 8 percent, re-routing most of the water to subsurface flow pathways;
- Reduced wind erosion by 44 percent, from 1.5 tons per acre without conservation practices to 0.85 ton per acre with conservation practices;
- Reduced sediment loss from fields by 47 percent, from 1.2 tons per acre without conservation practices to 0.6 ton per acre with conservation practices;
- Decreased the percentage of acres that are losing soil organic carbon from 63 percent to 54 percent;
- Reduced total nitrogen loss (volatilization, denitrification, surface runoff, and subsurface flow losses) from fields by 28 percent, from 65 pounds per acre without conservation practices to 47 pounds per acre with conservation practices:
    - Reduced nitrogen lost with surface runoff (attached to sediment and in solution) by 43 percent, from 10.6 pounds per acre without conservation practices to 6.1 pounds per acre with conservation practices;
    - Reduced nitrogen loss in subsurface flows by 30 percent, from 37 pounds per acre without conservation practices to 26 pounds per acre with conservation practices;
- Reduced total phosphorus loss from fields by 39 percent, from 5.36 pounds per acre without conservation practices to 3.25 pounds per acre with conservation practices; 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 aquatic ecosystems and a 26-percent reduction in edge-of-field pesticide risk for humans.

The relatively high losses of nitrogen in subsurface flows results from a combination of incomplete nutrient management and the re-routing of surface water runoff to subsurface flows by water erosion control practices on some acres in the region. On 25 percent of the cropped acres, nitrogen losses in subsurface flows increase as a result of conservation practices, although most increases are small. 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.

For land in long-term conserving cover (593,000 acres), soil erosion and sediment loss have been almost completely eliminated. Compared to a cropped condition without conservation practices, total nitrogen loss has been reduced by 77 percent, total phosphorus loss has been reduced by 88 percent, and the change in soil organic carbon has been increased by an average of 326 pounds per acre per year.

Conservation Treatment Needs

The adequacy of conservation practices in use in the Great Lakes region for the time period 2003-06 was evaluated to identify conservation treatment needs for five resource concerns:

- wind erosion,
- sediment loss from fields,
- nitrogen lost with surface runoff (attached to sediment and in solution),
- nitrogen loss in subsurface flows, and
- 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.

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

The resource concern with the most widespread need for additional conservation treatment related to cultivated cropland in the region is nitrogen loss in subsurface flows. About 16 percent of the acres in the region have a "high" need for additional nutrient management to address this concern, and an additional 29 percent have a "moderate" need. The proportion of cropped acres with a "high" or "moderate" need for additional conservation treatment for other resource concerns was determined to be—

- 6 percent for sediment loss (4 percent with a "high" need for treatment),
- 6 percent for nitrogen loss with runoff (no acres with a "high" need for treatment),
- 12 percent for phosphorus lost to surface water (no acres with a "high" need for treatment),
- 2 percent for wind erosion (no acres with a "high" need for treatment).

Some acres require additional treatment for only one of the five resource concerns, while other acres require additional treatment for two or more resource concerns. After accounting for acres that need treatment for multiple resource concerns, the evaluation of treatment needs for the Great Lakes Region determined the following :

- 19 percent of cropped acres (2.8 million acres) have a "high" level of need for additional conservation treatment for one or more resource concerns.
- 34 percent of cropped acres (5.0 million acres) have a "moderate" level of need for additional conservation treatment for one or more resource concerns.
- 47 percent of cropped acres (6.9 million acres) have a "low" level of need for additional treatment and are considered to be adequately treated.

Acres with a "high" level of need for conservation treatment lose (per acre per year, on average)—

- 1.1 tons of sediment by water erosion,
- 2.7 pounds of phosphorus,
- 7 pounds of nitrogen with surface runoff,
- 49 pounds of nitrogen in subsurface flows, and
- 1.6 tons of soil by wind erosion.

Acres with a "moderate" level of need for conservation treatment lose (per acre per year, on average)—
- 0.7 ton of sediment by water erosion,
- 2.6 pounds of phosphorus,
- 7 pounds of nitrogen with surface runoff,
- 28 pounds of nitrogen in subsurface flows, and
- 0.7 ton of soil by wind erosion.

Acres with a "low" level of need for conservation treatment lose (per acre per year, on average)—
- 0.4 ton of sediment by water erosion,
- 1.5 pounds of phosphorus,
- 5 pounds of nitrogen with surface runoff,
- 15 pounds of nitrogen in subsurface flows, and
- 0.6 ton of soil by wind erosion.

About 78 percent of the under-treated acres are under-treated for only one of the five resource concerns, usually nitrogen leaching:
- 68 percent of under-treated acres are under-treated only for nitrogen leaching,
- 8 percent of under-treated acres are under-treated only for phosphorus runoff, and
- less than 1 percent of under-treated acres are under-treated only for sediment loss.

Nitrogen leaching and phosphorus runoff was the most frequently occurring combination of resource concerns, representing 9 percent of under-treated acres. Only about 3 percent of under-treated acres were determined to be under-treated for all of the resource concerns except wind erosion.

Acres with a "high" level of treatment need are disproportionately high in two basins: Western Lake Michigan and Eastern Lake Michigan. In contrast, the Lake Erie basin has a disproportionately low share of acres with a "high" level of treatment need. Only 17 percent of the critical under-treated acres in the region are found in this basin, whereas the basin has 38 percent of the region's cropped acres. Only 8 percent of the cropped acres in the Lake Erie basin have a "high" need for additional treatment.

Under-treated acres for sediment loss are proportionately highest in the Lake Ontario basin, where 11 percent of cropped acres have a "high" level of treatment need for sediment loss, compared to the regional average of 4 percent. An additional 5 percent of the cropped acres in this region have a moderate need for additional treatment for sediment loss. The Lake Ontario basin also has the highest proportion of acres needing treatment for nitrogen lost with surface runoff (16 percent compared to the regional average of 6 percent) and for phosphorus loss (28 percent compared to the regional average of 12 percent). The Western Lake Michigan basin has relatively high proportions of conservation treatment needs for nitrogen lost with surface runoff (12 percent of cropped acres) and phosphorus loss (20 percent of cropped acres).

Critical under-treated acres for nitrogen loss in subsurface flows are lowest in the Lake Erie basin—only 6 percent of cropped acres compared to the regional average of 16 percent.

Under-treated acres for wind erosion control are primarily in the Lake Huron basin, where 7.5 percent of cropped acres have a moderate need for additional treatment.

Simulation of Additional Conservation Treatment

Additional conservation treatment was simulated for: 1) the 2.84 million acres in the region with a "high" treatment need (critical under-treated acres), and 2) all 7.9 million under-treated acres. Two levels of treatment were simulated for each set of acres:
- *Treatment with additional erosion control practices*, which consisted of adding in-field practices to control overland flow (terraces, contouring, or stripcropping) for acres without overland flow control practices and having a slope of more than 2 percent, adding edge-of-field buffering or filtering practices to all acres without edge-of-field practices, and adding wind erosion control practices for sample points where wind erosion exceeded an average of 4 tons per acre per year in the baseline.
- *Treatment with nutrient management in addition to erosion control practices*, which was modeled by adjusting the commercial fertilizer and manure applications to simulate the appropriate rate of application, the appropriate timing of application, and use of the appropriate application method.

Model simulation 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 *required* to simultaneously address 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 re-routing of soluble nitrogen and phosphorus to subsurface loss pathways.

Treatment of the 2.84 million acres with a "high" need for additional treatment would achieve the following gains ***for the region as a whole*** *when treated with both soil erosion control practices and nutrient management practices where needed*:
- Wind erosion would average 0.74 ton per acre per year, compared to the baseline conservation condition average of 0.85 ton per acre per year (a 13-percent reduction).
- Sediment loss from fields would average 0.44 ton per acre per year, compared to the baseline conservation condition average of 0.63 ton per acre per year (a 30-percent reduction).
- Nitrogen lost from the field with surface runoff (attached to sediment and in solution) would average 5.0 pounds per acre per year, compared to the baseline conservation condition average of 6.1 pounds per acre per year (a 17-percent reduction).

- Nitrogen loss from the field in subsurface flows would average 21 pounds per acre per year, compared to the baseline conservation condition average of 26 pounds per acre per year (a 30-percent reduction).
- Total phosphorus loss, most of which is lost to surface water, would average 2.7 pounds per acre per year, compared to 3.2 pounds per acre per year for the baseline conservation condition (a 16-percent reduction).
- Environmental risk from the loss of pesticide residues would be reduced about 5 to 10 percent.

Treatment of all 7.9 million under-treated acres would achieve the following gains ***for the region as a whole*** *when treated with both soil erosion control practices and nutrient management practices where needed*:

- Wind erosion would average 0.68 ton per acre per year, compared to the baseline conservation condition average of 0.85 ton per acre per year (a 20-percent reduction).
- Sediment loss from fields would average 0.23 ton per acre per year, compared to the baseline conservation condition average of 0.63 ton per acre per year (a 64-percent reduction).
- Nitrogen lost from the field with surface runoff (attached to sediment and in solution) would average 3.5 pounds per acre per year, compared to the baseline conservation condition average of 6.1 pounds per acre per year (a 42-percent reduction).
- Nitrogen loss from the field in subsurface flows would average 16 pounds per acre per year, compared to the baseline conservation condition average of 26 pounds per acre per year (a 38-percent reduction).
- Total phosphorus loss, most of which is lost to surface water, would average 2.1 pounds per acre per year, compared to 3.2 pounds per acre per year for the baseline conservation condition (a 36-percent reduction).
- Environmental risk from the loss of pesticide residues would be reduced about 13 to 17 percent.

Not all acres get the same benefit from conservation treatment. The more vulnerable acres, such as highly erodible land and soils prone to leaching, inherently lose more sediment and/or nutrients, and therefore greater benefit can be attained with conservation treatment. The gains in efficiency by first treating the 2.84 million critical under-treated acres would—

- reduce sediment loss an average of 1 ton per acre per year on those acres, compared to 0.63 ton per acre per year for additional treatment of the remaining 5.04 million under-treated acres and only 0.35 ton per acre per year for treatment of the 6.92 million adequately treated acres, on average;
- reduce wind erosion an average of 0.59 ton per acre per year on those acres, compared to 0.18 ton per acre per year for additional treatment of the remaining 5.04 million under-treated acres and only 0.15 ton per acre per year for treatment of the 6.92 million adequately treated acres, on average.
- reduce total nitrogen loss an average of 37 pounds per acre per year on those acres, compared to 22 pounds per acre per year for additional treatment of the remaining 5.04 million under-treated acres and only 6.5 pounds per acre per year for treatment of the 6.92 million adequately treated acres, on average; and
- reduce total phosphorus loss an average of 2.8 pounds per acre per year on those acres, compared to 1.9 pounds per acre per year for additional treatment of the remaining 5.04 million under-treated acres and only 0.9 pound per acre per year for treatment of the 6.92 million adequately treated acres, on average.

Conservation Practice Effects on Water Quality

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

Cultivated cropland represents about 24 percent of the land base in the Great Lakes Region. At the 2003–06 level of conservation practice use, cultivated cropland delivered a disproportionate amount of sediment and nutrients to rivers and streams and ultimately to the Lakes. Of the total loads <u>delivered to rivers and streams</u> from all sources, cultivated cropland is the source for 43 percent of the sediment, 45 percent of the nitrogen, and 47 percent of the phosphorus.

Figures 94, 95, and 96 summarize the extent to which conservation practices on cultivated cropland acres have reduced, and can further reduce, sediment, nitrogen, and phosphorus loads in the Great Lakes Region, on the basis of the model simulations.

In each figure, the top map shows delivery from cultivated cropland to rivers and streams within the region and the bottom map shows delivery from all sources to the Lakes after accounting for losses and gains through instream processes.

The effects of practices in use during 2003–06 are seen by contrasting loads for the baseline conservation condition to loads for the no-practice scenario. The effects of additional conservation treatment on loads are seen by contrasting the loads for the baseline condition to either—

1. loads for treatment of acres with a "high" level of treatment need (2.84 million critical under-treated acres), or
2. loads for treatment of all under-treated acres (7.9 million acres with either a "high" or moderate level of treatment need).

Background levels, representing loads that would be expected if no acres in the watershed were cultivated, are also shown in the bar charts. These estimates simulate a grass and tree mix cover without any tillage or addition of nutrients or pesticides for all cultivated cropland acres in the watershed. Background loads also include loads from all other land uses—hayland, pastureland, forestland, and urban land—as well as point sources.

Sediment loss

In figure 94, the top map shows that the use of conservation practices has reduced ***sediment loads delivered from cropland to rivers and streams*** in the region by 50 percent from conditions that would be expected without conservation practices. Application of additional conservation practices would reduce baseline sediment loads delivered to rivers and streams within the region by 25 percent by treating acres with a “high” level of treatment need. Treating ALL under-treated acres (acres with either a “high” or “moderate” need for treatment) would reduce baseline sediment loads delivered to rivers and streams within the region by 58 percent.

The bottom map shows that the use of conservation practices on cropland has reduced ***sediment loads delivered to the Lakes from all sources*** by 12 percent from conditions that would be expected without conservation practices. Application of additional conservation practices would reduce baseline sediment loads delivered to the Lakes by 4 percent by treating acres with a “high” level of treatment need. Treating ALL under-treated acres (acres with either a” high” or “moderate” need for treatment) would reduce baseline sediment loads delivered to the Lakes by 9 percent.

Total nitrogen loss

In figure 95, the top map shows that the use of conservation practices has reduced ***total nitrogen loads delivered from cropland to rivers and streams*** in the region by 37 percent from conditions that would be expected without conservation practices. Application of additional conservation practices would reduce baseline total nitrogen loads delivered to rivers and streams within the region by 18 percent by treating acres with a “high” level of treatment need. Treating ALL under-treated acres (acres with either a” high” or “moderate” need for treatment) would reduce baseline nitrogen loads delivered to rivers and streams within the basin by 37 percent.

The bottom map shows that the use of conservation practices on cropland has reduced ***total nitrogen loads delivered to the Lakes from all sources*** by 21 percent from conditions that would be expected without conservation practices. Application of additional conservation practices would reduce baseline total nitrogen loads delivered to the Lakes by 8 percent by treating acres with a “high” level of treatment need. Treating ALL under-treated acres (acres with either a “high” or “moderate” need for treatment) would reduce baseline nitrogen loads delivered to the Lakes by 16 percent.

Total phosphorus loss

In figure 96, the top map shows that the use of conservation practices has reduced ***total phosphorus loads delivered from cropland to rivers and streams*** in the region by 36 percent from conditions that would be expected without conservation practices. Application of additional conservation practices would reduce baseline total phosphorus loads delivered to rivers and streams by 11 percent by treating acres with a “high” level of treatment need. Treating ALL under-treated acres (acres with either a “high” or “moderate” need for treatment) would reduce baseline phosphorus loads delivered to rivers and streams within the basin by 33 percent.

The bottom map shows that the use of conservation practices on cropland has reduced ***total phosphorus loads delivered to the Lakes from all sources*** by 20 percent from conditions that would be expected without conservation practices. Application of additional conservation practices would reduce baseline total phosphorus loads delivered to the Lakes by 5 percent by treating acres with a “high” level of treatment need. Treating ALL under-treated acres (acres with either a “high” or “moderate” need for treatment) would reduce baseline phosphorus loads delivered to the Lakes by 15 percent.

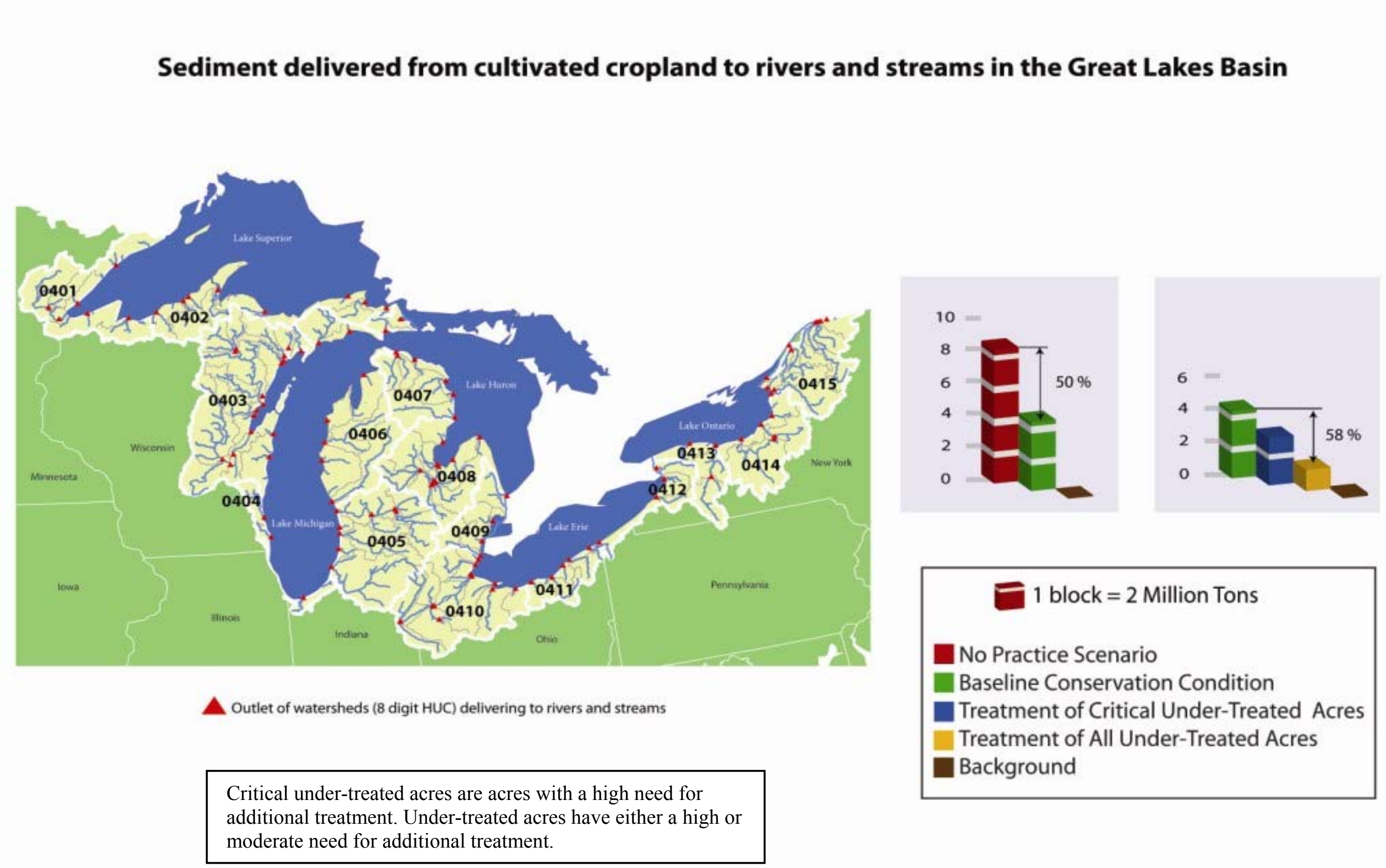
Atrazine loss

Although the full suite of pesticides was modeled for edge-of-field losses, atrazine was the only pesticide for which in-stream loads were assessed because it was the dominant contributor to mass loss of pesticide residues from farm fields and the primary contributor to environmental risk from pesticides in the region. Cultivated cropland was the only source for atrazine in the model simulations.

The use of conservation practices has reduced ***atrazine loads delivered from cropland to rivers and streams*** within the region by 24 percent from conditions that would be expected without conservation practices. The use of conservation practices on cropland has also reduced ***atrazine loads delivered to the Lakes*** by 23 percent.

Application of additional erosion control and nutrient management conservation practices would reduce baseline atrazine loads delivered to the Lakes by 4 percent by treating acres with a “high” level of treatment need. Treating ALL under-treated acres (acres with either a “high” or “moderate” need for treatment) would reduce baseline atrazine loads delivered to the Lakes by 11 percent.

Figure 94. Summary of the effects of conservation practices on sediment loads in the Great Lakes Region



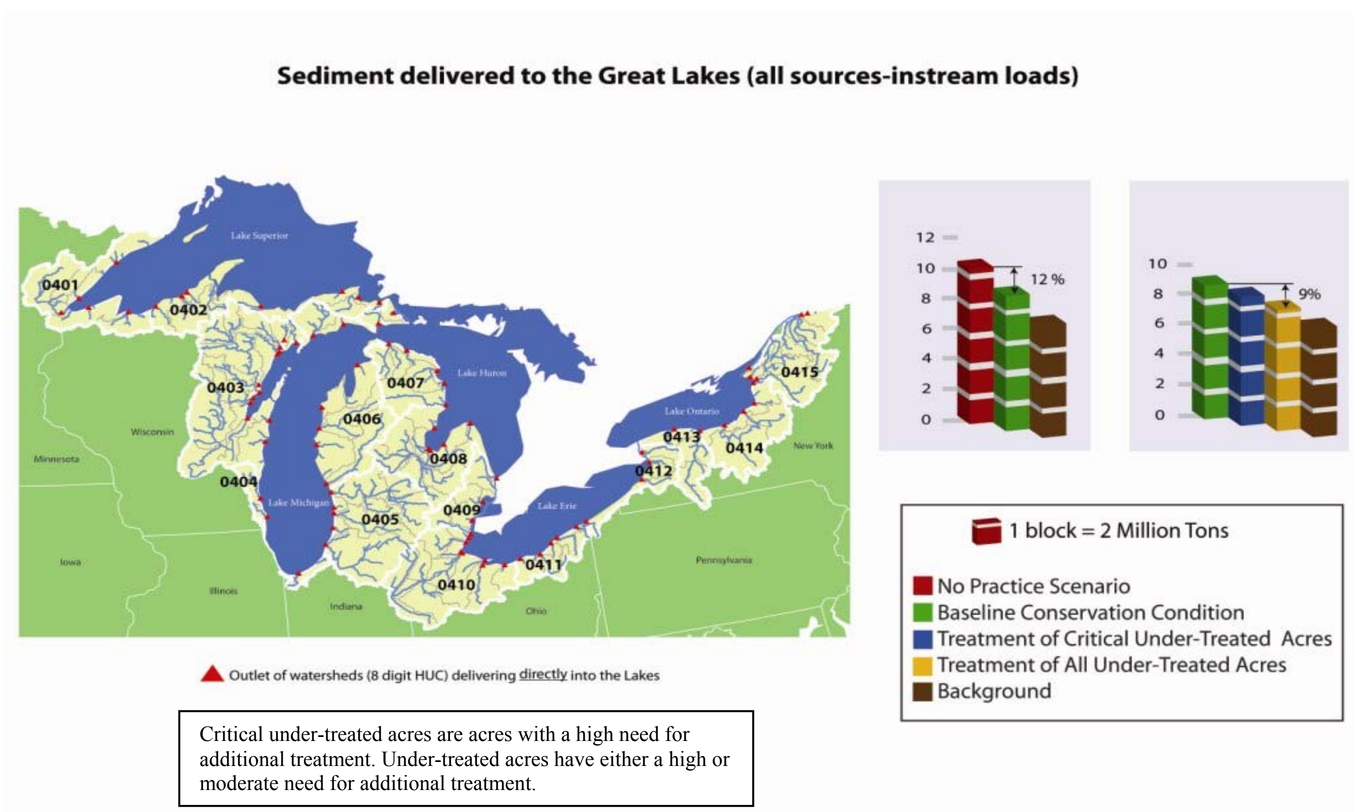
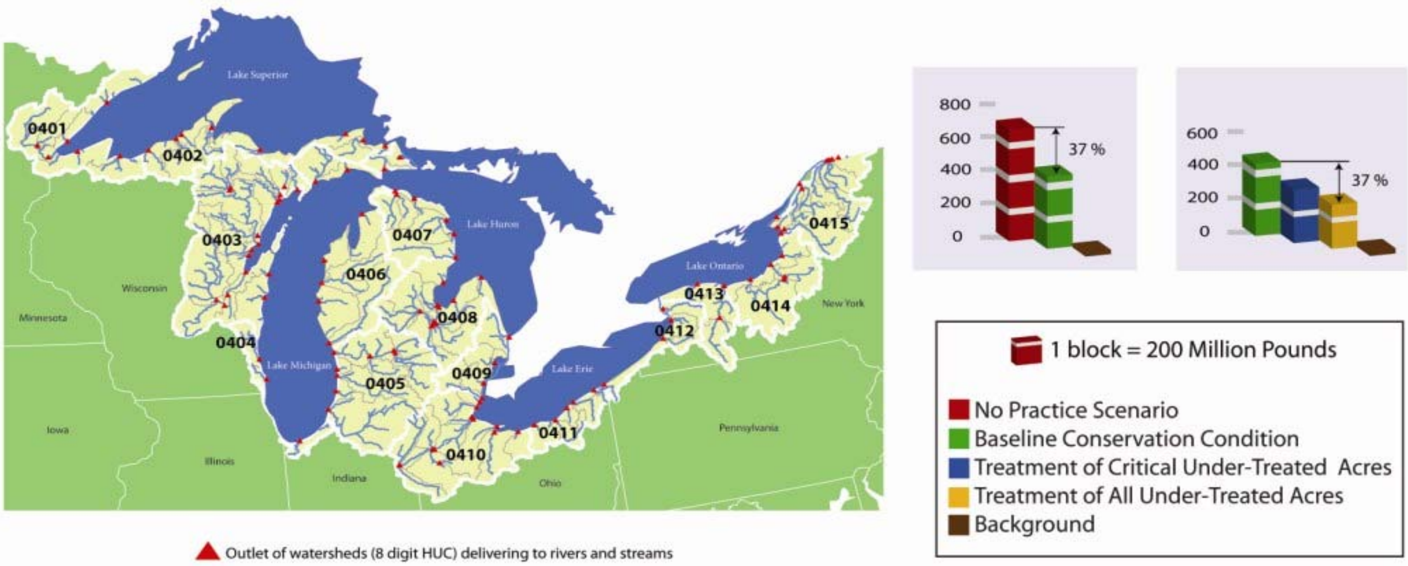


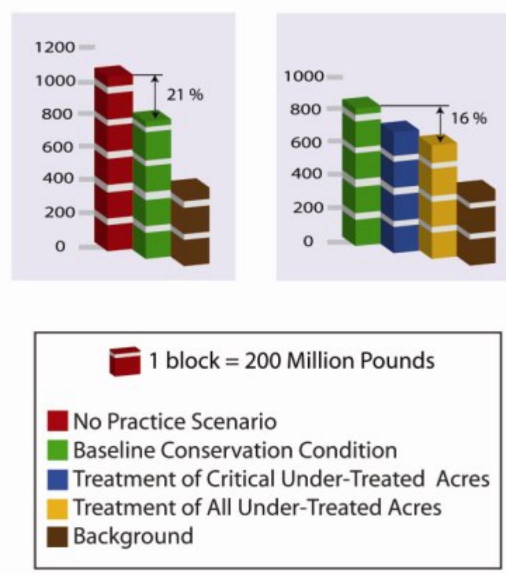
Figure 95. Summary of the effects of conservation practices on total nitrogen loads in the Great Lakes Region

Nitrogen delivered from cultivated cropland to rivers and streams in the Great Lakes Basin



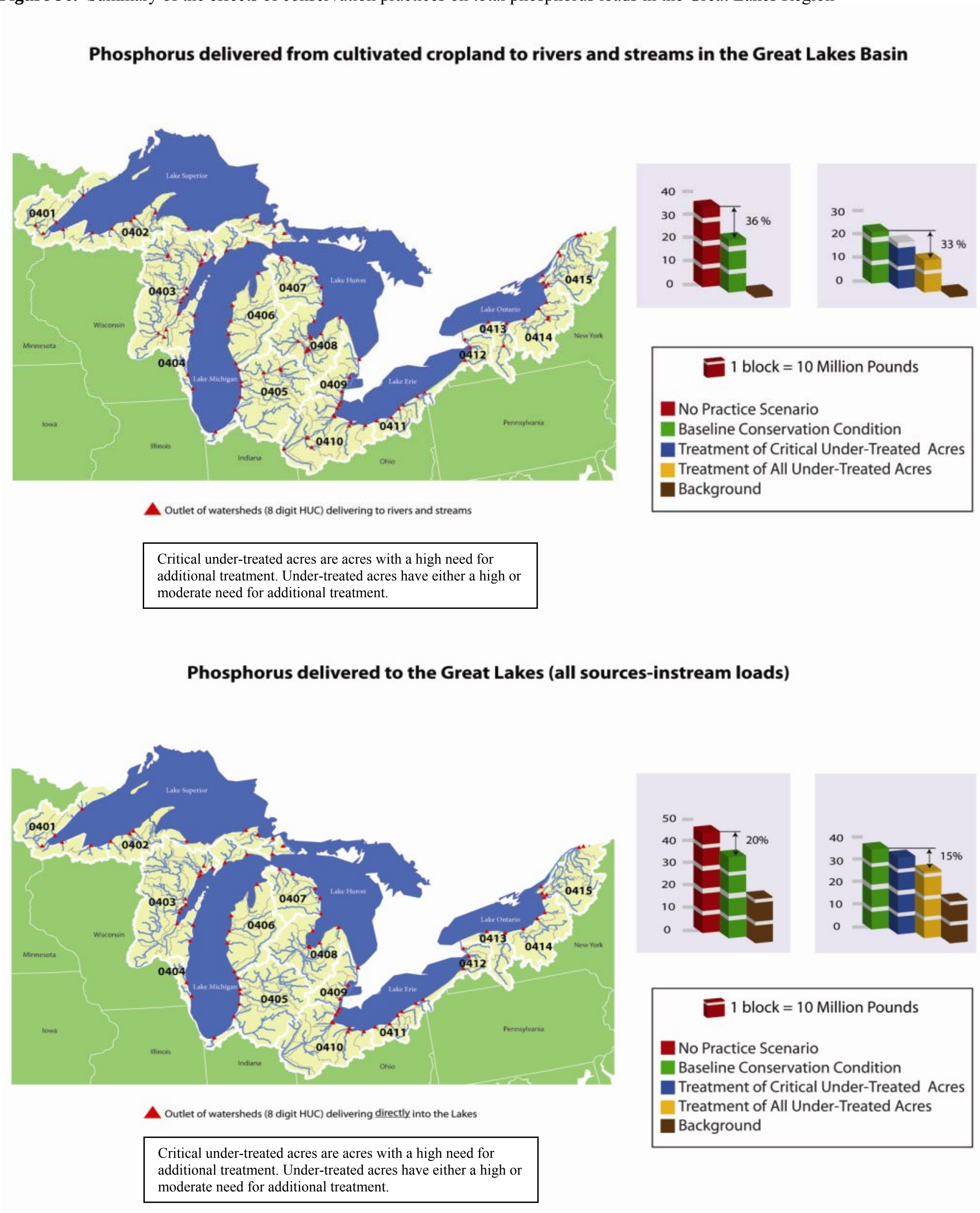
Critical under-treated acres are acres with a high need for additional treatment. Under-treated acres have either a high or moderate need for additional treatment.

Nitrogen delivered to the Great Lakes (all sources-instream loads)



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

Figure 96. Summary of the effects of conservation practices on total phosphorus loads in the Great Lakes Region



References

Arnold, J.G., R. Srinivasan, R.S. Muttiah, and J.R. Williams. 1998. Large area hydrologic modeling and assessment part I: model development. *Journal of the American Water Resources Association*. 34(1): 73-89.

Arnold, J.G., R. Srinivasan, R.S. Muttiah, and P.M. Allen. 1999. Continental scale simulation of the hydrologic balance. *Journal of the American Water Resources Association*. 35(5): 1037-1052.

Arnold, J.G. and N. Fohrer. 2005. SWAT2000: current capabilities and research opportunities in applied watershed modeling. *Hydrological Processes*. 19(3): 563-572.

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.

Duriancik, L.F., D. Bucks, J.P. Dobrowolski, T. Drewes, S.D. Eckles, L. Jolley, R.L. Kellogg, D. Lund, J.R. Makuch, M.P. O'Neill, C.A. Rewa, M.R. Walbridge, R. Parry, and M. Weltz. 2008. The first five years of the Conservation Effects Assessment Project. Journal of Soil and Water Conservation, Nov.-Dec. 2008.

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., M.R. Reyes, C.H. Green, and J.G. Arnold. 2007. The Soil and Water Assessment Tool: Historical development, applications and future research directions. Transactions of the American Society of Agricultural and Biological Engineers 50(4): 1211-1250.

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* (forthcoming).

Gianessi, L.P., and H.M. Peskin. 1984. An overview of the RFF Environmental Data Inventory--Methods and preliminary results: Resources for the Future, Washington, D.C., 111 p.

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.

Huber, W.C. and R.E. Dickinson. 1988. Storm water management model, version 4: user's manual.

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/

NADP/NTN, 2004. National Atmospheric Deposition Program / National Trends Network, http://nadp.sws.uiuc.edu

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 (verified 8 June 2008).

Srinivasan, R.S., J.G. Arnold, and C.A. Jones. 1998. Hydrologic modeling of the United States with the Soil and Water Assessment Tool. *International Journal of Water Resources Development*. 14(3): 315-325.

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

USDA-Farm Service Agency. June 2004. Conservation Reserve Program Overview. CRP: Planting for the Future. U.S. Department of Agriculture, Farm Service Agency. Washington, DC.

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

Wiebe, Keith, and Noel Gollehon, editors. July 2006. Agricultural Resources and Environmental Indicators, 2006 Edition. Chapter 5, Conservation and Environmental Policies—USDA Land Retirement Programs. Economic Information Bulletin Number 16. U.S. Department of Agriculture, Economic Research Service. 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 "NRI-CEAP Cropland Survey Design and Statistical Documentation," available at http://www.nrcs.usda.gov/technical/nri/ceap.)
The sample for cropped acres consists of 1,418 sample points in the Great Lakes Region. Acres reported using the CEAP sample are "estimated" acres because of the uncertainty associated with statistical sampling.

Statistics derived from the CEAP database are based upon data collected at sample sites located across all parts of the region. This means that estimates of acreage are statistical estimates and contain some amount of statistical uncertainty. Since the NRI employs recognized statistical methodology, it is possible to quantify this statistical uncertainty.

Margins of error are provided in table A1 for selected acres estimates found elsewhere in the report. The margin of error is a commonly used measure of statistical uncertainty and can be used to construct a 95-percent confidence interval for an estimate. The lower bound of the confidence interval is obtained by subtracting the margin of error from the estimate; adding the margin of error to the estimate forms the upper bound. Measures of uncertainty (e.g., margins of error, standard errors, confidence intervals, coefficients of variation) should be taken into consideration when using CEAP acreage estimates. The margin of error is calculated by multiplying the standard error by the factor 1.96; a coefficient of variation is the relative standard for an estimate, usually in terms of percentages, and is calculated by taking 100 times the standard error and then dividing by the estimate.

The precision of CEAP 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.

Note that the CEAP sample size for the Lake Superior basin was too small to report cropped acres separately for that basin in table A1.

Table A1. Margins of error for acre estimates based on the CEAP sample

	Estimated acres	Margin of error
Cropped Acres		
Western Lake Michigan Basin including Fox River	2,303,100	234,651
Eastern Lake Michigan Basin	3,465,900	373,707
Lake Huron Basin	2,086,400	278,146
Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	5,659,600	414,033
Lake Ontario Basin including Oswego-St. Lawrence Rivers	1,281,200	176,235
Total for Great Lakes Region	14,803,500	552,913
Highly erodible land (HEL)		
Western Lake Michigan Basin including Fox River	454,980	157,033
Eastern Lake Michigan Basin	687,951	199,240
Lake Huron Basin	127,220	103,243
Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	818,069	206,653
Lake Ontario Basin including Oswego-St. Lawrence Rivers	392,649	159,926
Total for Great Lakes Region	2,480,869	285,933
Acres receiving manure		
Western Lake Michigan Basin including Fox River	860,694	192,014
Eastern Lake Michigan Basin	489,177	123,429
Lake Huron Basin	434,283	199,222
Lake Erie Basin including St. Clair-Detroit-Clinton-Huron Rivers	571,180	150,439
Lake Ontario Basin including Oswego-St. Lawrence Rivers	437,071	173,420
Total for Great Lakes Region	2,799,705	407,195

Table A1—continued.

	Estimated acres	Margin of error
Cropping systems (table 5)		
Corn-soybean only	5,894,702	520,516
Corn-soybean with close grown crops	1,890,721	272,902
Corn only	1,556,955	282,036
Soybean only	714,208	149,857
Soybean-wheat only	1,048,777	259,107
Corn and close grown crops	484,652	160,912
Vegetable or tobacco with or without other crops	1,091,770	265,161
Hay-crop mix	1,628,555	417,100
Remaining mix of crops	493,160	138,890
Use of structural practices (table 6)		
Overland flow control practices	1,363,968	237,178
Concentrated flow control practices	1,785,033	282,145
Edge-of-field buffering and filtering practices	1,718,302	259,187
One or more water erosion control practices	3,909,475	413,243
Wind erosion control practices	619,091	158,656
Use of cover crops	157,206	97,971
Use of residue and tillage management (table 7)		
Average annual tillage intensity for crop rotation meets criteria for no-till	4,725,474	518,875
Average annual tillage intensity for crop rotation meets criteria for mulch till	7,465,098	630,226
Reduced tillage on some crops in rotation but average annual tillage intensity greater than criteria for mulch till	1,268,423	324,241
Continuous conventional tillage in every year of crop rotation	1,344,504	249,990
Use of structural practices and/or residue and tillage management (table 8)		
No-till or mulch till with carbon gain, no structural practices	4,485,644	414,952
No-till or mulch till with carbon loss, no structural practices	4,443,649	396,466
Some crops with reduced tillage, no structural practices	1,067,532	298,519
Structural practices and no-till or mulch till with carbon gain	1,904,408	267,083
Structural practices and no-till or mulch till with carbon loss	1,356,872	259,843
Structural practices and some crops with reduced tillage	200,892	145,089
Structural practices only	447,303	210,861
No water erosion control treatment	897,201	189,440
Conservation treatment levels for structural practices (fig. 7)		
High level of treatment	647,860	176,939
Moderately high level of treatment	1,311,799	295,715
Moderate level of treatment	1,949,816	330,703
Low level of treatment	10,894,025	653,162
Conservation treatment levels for residue and tillage management (fig. 8)		
High level of treatment	5,308,739	515,123
Moderately high level of treatment	1,084,985	283,325
Moderate level of treatment	7,302,504	496,910
Low level of treatment	1,107,273	239,145

Table A1—continued.

	Estimated acres	Margin of error
Conservation treatment levels for nitrogen management (fig. 9)		
High level of treatment	2,611,952	367,625
Moderately high level of treatment	4,008,209	428,988
Moderate level of treatment	6,783,126	540,651
Low level of treatment	1,400,213	374,100
Conservation treatment levels for phosphorus management (fig. 10)		
High level of treatment	4,510,893	536,070
Moderately high level of treatment	2,440,691	362,202
Moderate level of treatment	2,972,773	415,057
Low level of treatment	4,879,143	461,243
Conservation treatment levels for IPM (fig. 11)		
High level of treatment	855,373	220,600
Moderate level of treatment	5,901,260	570,034
Low level of treatment	8,046,867	501,956
Conservation treatment levels for water erosion control practices (fig. 49)		
High level of treatment	4,234,072	424,007
Moderately high level of treatment	1,223,577	290,538
Moderate level of treatment	5,971,780	539,699
Low level of treatment	3,374,071	512,163
Conservation treatment levels for nitrogen runoff control (fig. 50)		
High level of treatment	666,275	192,357
Moderately high level of treatment	4,713,887	462,962
Moderate level of treatment	7,190,926	409,069
Low level of treatment	2,232,412	446,690
Conservation treatment levels for phosphorus runoff control (fig. 51)		
High level of treatment	1,071,293	247,134
Moderately high level of treatment	4,055,809	415,484
Moderate level of treatment	6,296,456	530,956
Low level of treatment	3,379,942	344,509
Conservation treatment levels for wind erosion management (fig. 52)		
High level of treatment	383,734	123,014
Moderately high level of treatment	4,816,555	536,862
Moderate level of treatment	7,081,937	621,841
Low level of treatment	2,521,273	383,103
Soil runoff potential (fig. 53)		
High	941,980	216,312
Moderately high	3,195,974	395,140
Moderate	2,855,299	232,188
Low	7,810,247	593,926
Soil leaching potential (fig. 55)		
High	2,188,863	325,895
Moderately high	2,278,319	348,814
Moderate	7,423,964	527,326
Low	2,912,354	322,460
Wind erosion potential (fig. 57)		
High	79,841	58,449
Moderately high	481,717	157,660
Moderate	817,920	242,493
Low	13,424,022	502,321

Table A1—continued.

	Estimated acres	Margin of error
Level of conservation treatment need by resource concern		
Wind erosion (table 27)		
High (critical under-treated)	0	--
Moderate (non-critical under-treated)	253,036	159,235
Low (adequately treated)	14,550,464	520,234
Sediment loss (table 23)		
High (critical under-treated)	567,522	160,396
Moderate (non-critical under-treated)	315,012	121,044
Low (adequately treated)	13,920,966	565,134
Nitrogen loss with surface runoff (sediment attached and soluble) (table 24)		
High (critical under-treated)	0	
Moderate (non-critical under-treated)	901,857	209,789
Low (adequately treated)	13,901,643	564,209
Nitrogen loss in subsurface flows (table 25)		
High (critical under-treated)	2,384,897	349,646
Moderate (non-critical under-treated)	4,331,286	495,584
Low (adequately treated)	8,087,317	487,181
Phosphorus lost to surface water (table 26)		
High (critical under-treated)	0	
Moderate (non-critical under-treated)	1,739,869	307,571
Low (adequately treated)	13,063,631	569,088
Level of conservation treatment need for one or more resource concerns		
Great Lakes Region (table 31)		
High (critical under-treated)	2,842,314	352,034
Moderate (non-critical under-treated)	5,036,722	508,011
Low (adequately treated)	6,924,465	428,725
Western Lake Michigan (table 31)		
High (critical under-treated)	592,694	216,870
Moderate (non-critical under-treated)	650,995	114,484
Low (adequately treated)	1,059,411	229,649
Eastern Lake Michigan (table 31)		
High (critical under-treated)	873,752	225,816
Moderate (non-critical under-treated)	981,430	233,641
Low (adequately treated)	1,610,718	225,955
Lake Huron(table 31)		
High (critical under-treated)	497,823	184,685
Moderate (non-critical under-treated)	671,953	212,684
Low (adequately treated)	916,623	215,962
Lake Erie (table 31)		
High (critical under-treated)	469,606	126,728
Moderate (non-critical under-treated)	2,219,772	411,427
Low (adequately treated)	2,970,222	297,405
Lake Ontario (table 31)		
High (critical under-treated)	408,439	121,360
Moderate (non-critical under-treated)	505,271	134,972
Low (adequately treated)	367,490	103,542

Appendix B: Model Simulation Results for the Baseline Conservation Condition for Basins in the Great Lakes Region

Model simulation results presented in Chapter 4 for the baseline conservation condition are presented in tables B1 and B2 for five of the six basins in the Great Lakes Region. The CEAP sample size for the Lake Superior basin was too small to report cropped acres separately for that basin in these tables.

Table B1. Basin characteristics and average annual estimates of water flow, erosion, and soil organic carbon for the baseline conservation condition for cropped acres, by basin, in the Great Lakes Region

Model simulated outcome	Great Lakes Region	Western Lake Michigan	Eastern Lake Michigan	Lake Huron	Western Lake Erie subregion (code 0410)	Other Lake Erie, subregions (codes 0409, 0411, and 0412)	Lake Ontario
CEAP sample size for estimating cropped acres	1,418	226	362	125	492	100	112
Cropped acres (million acres)	14.803	2.303	3.466	2.086	4.802	0.858	1.281
Percent of acres in region	100%	41%	23%	14%	32%	6%	9%
Percent of acres highly erodible	17%	20%	20%	6%	13%	17%	31%
Percent of acres irrigated	4%	1%	13%	2%	1%	2%	1%
Percent of acres receiving manure	19%	37%	14%	21%	8%	20%	34%
Water sources (average annual inches)							
Non-irrigated acres							
Precipitation	34	31	34	30	35	34	36
Irrigated acres							
Precipitation	35	31	36	30	35	37	42
Irrigation water applied	8	11	8	10	10	5	2
Water loss pathways (average annual inches)							
Evapotranspiration	21.6	20.8	21.5	19.5	23.0	21.5	21.3
Surface water runoff	4.5	3.6	4.4	3.4	4.7	5.3	6.6
Subsurface water flow	7.9	7.1	9.9	7.4	7.0	7.8	8.7
Erosion and sediment loss (average annual tons/acre)							
Wind erosion	0.85	0.44	1.47	2.40	0.15	0.80	0.07
Sheet and rill erosion	0.44	0.74	0.29	0.19	0.32	0.61	1.05
Sediment loss at edge of field due to water erosion	0.63	0.87	0.43	0.24	0.44	0.91	1.92
Soil organic carbon (average annual pounds/acre)							
Loss of soil organic carbon with wind and water erosion	179	129	224	239	142	179	188
Change in soil organic carbon, including loss of carbon with wind and water erosion	-58	-54	-126	-139	66	-91	-195

Table B2. Average annual estimates of nitrogen loss, phosphorus loss, and pesticide loss for the baseline conservation condition for cropped acres, by basin, in the Great Lakes Region

Model simulated outcome	Great Lakes Region	Western Lake Michigan	Eastern Lake Michigan	Lake Huron	Western Lake Erie subregion (code 0410)	Other Lake Erie, subregions (codes 0409, 0411, and 0412)	Lake Ontario
Nitrogen (average annual pounds/acre)							
Nitrogen sources							
Atmospheric deposition	8.0	8.1	8.1	7.8	7.9	7.7	9.0
Bio-fixation by legumes	48.0	44.0	46.4	35.9	62.7	53.4	20.9
Nitrogen applied as commercial fertilizer and manure	77.5	77.1	73.5	82.2	76.3	59.2	98.6
All nitrogen sources	133.6	129.2	127.9	125.9	147.0	120.3	128.5
Nitrogen in crop yield removed at harvest	95.6	94.4	93.3	84.9	107.4	93.1	78.6
Nitrogen loss pathways							
Nitrogen loss by volatilization	7.0	5.7	7.4	6.4	8.2	6.3	5.4
Nitrogen loss through denitrification	2.5	2.2	2.7	1.4	3.4	1.2	1.8
Nitrogen lost with windborne sediment	5.3	2.4	9.1	14.4	1.5	4.6	0.4
Nitrogen loss with surface runoff , including waterborne sediment	6.1	6.6	4.6	3.1	5.9	7.5	13.8
Nitrogen loss in subsurface flow pathways	25.8	24.3	26.6	30.9	19.3	18.6	47.6
Total nitrogen loss for all loss pathways	46.7	41.2	50.2	56.1	38.3	38.2	69.0
Change in soil nitrogen	-10.4	-8.6	-17.1	-16.7	-0.2	-13.2	-21.5
Phosphorus (average annual pounds/acre)							
Phosphorus applied as commercial fertilizer and manure	20.7	20.2	17.9	19.1	21.2	20.9	29.7
Phosphorus in crop yield removed at harvest	14.7	13.5	15.1	12.9	16.2	14.0	12.9
Phosphorus loss pathways							
Phosphorus lost with windborne sediment	1.13	0.51	1.99	3.02	0.26	1.09	0.11
Phosphorus lost to surface water, including waterborne sediment and soluble phosphorus in surface water runoff and lateral flow into drainage tiles and ditches and natural seeps	2.09	2.01	1.27	1.17	2.03	2.67	5.80
Soluble phosphorus loss to groundwater	0.03	0.04	0.05	0.02	0.01	0.03	0.04
Total phosphorus loss for all loss pathways	3.25	2.56	3.30	4.21	2.30	3.79	5.95
Change in soil phosphorus	2.8	4.0	-0.5	2.0	2.7	2.9	10.8
Pesticides							
Average annual amount of pesticides applied (grams of active ingredient/hectare)	1667	1075	2179	1473	1690	1139	1933
Pesticide loss							
Average annual mass loss of pesticides for all pathways (grams of active ingredient/hectare)	11	6	13	6	12	5	20
Edge-of-field pesticide risk indicator							
Average annual surface water pesticide risk indicator for aquatic ecosystem	1.9	1.1	2.5	0.6	2.8	0.7	1.5
Average annual surface water pesticide risk indicator for humans	0.4	0.3	0.6	0.1	0.6	0.2	0.4
Average annual groundwater pesticide risk indicator for humans	0.1	<0.1	0.2	0.1	0.1	0.0	0.1

Table B3. Percent of cropped acres for conservation treatment levels and soil vulnerability potentials, by basin, in the Great Lakes Region

Category	Great Lakes Region	Western Lake Michigan	Eastern Lake Michigan	Lake Huron	Western Lake Erie subregion (code 0410)	Other Lake Erie, subregions (codes 0409, 0411, and 0412)	Lake Ontario
Percent of cropped acres within basin at four conservation treatment levels for structural practices (see figure 7)							
High conservation treatment level	4%	4%	2%	3%	7%	4%	4%
Moderately-high conservation treatment level	9%	5%	7%	11%	13%	5%	6%
Moderate conservation treatment level	13%	14%	13%	7%	14%	14%	19%
Low conservation treatment level	74%	77%	78%	79%	66%	78%	71%
Percent of cropped acres within basin at four conservation treatment levels for residue and tillage management (see figure 8)							
High conservation treatment level	36%	20%	32%	10%	68%	16%	8%
Moderately-high conservation treatment level	7%	10%	3%	4%	10%	8%	7%
Moderate conservation treatment level	49%	57%	58%	74%	20%	66%	66%
Low conservation treatment level	7%	12%	6%	12%	1%	11%	18%
Percent of cropped acres within basin at four conservation treatment levels for nitrogen management (see figure 9)							
High conservation treatment level	18%	21%	18%	16%	12%	30%	25%
Moderately-high conservation treatment level	27%	38%	31%	22%	21%	38%	19%
Moderate conservation treatment level	46%	30%	43%	56%	56%	22%	45%
Low conservation treatment level	9%	11%	7%	7%	11%	9%	11%
Percent of cropped acres within basin at four conservation treatment levels for phosphorus management (see figure 10)							
High conservation treatment level	30%	33%	37%	35%	25%	35%	21%
Moderately-high conservation treatment level	16%	22%	20%	12%	17%	8%	9%
Moderate conservation treatment level	20%	14%	24%	20%	14%	26%	38%
Low conservation treatment level	33%	31%	19%	33%	44%	31%	33%
Percent of cropped acres within basin at four levels of soil runoff potential (see figure 53)							
High soil vulnerability potential	6%	11%	7%	1%	3%	8%	17%
Moderately high soil vulnerability potential	22%	33%	13%	16%	23%	22%	26%
Moderate soil vulnerability potential	19%	15%	12%	10%	31%	24%	13%
Low soil vulnerability potential	53%	40%	68%	73%	42%	46%	44%
Percent of cropped acres within basin at four levels of soil leaching potential (see figure 55)							
High soil vulnerability potential	15%	13%	25%	27%	5%	11%	7%
Moderately high soil vulnerability potential	15%	32%	17%	13%	5%	12%	27%
Moderate soil vulnerability potential	50%	49%	51%	39%	56%	42%	53%
Low soil vulnerability potential	20%	6%	7%	21%	34%	34%	13%
Percent of cropped acres within basin at four levels of soil wind erosion potential (see figure 57)							
High soil vulnerability potential	1%	1%	1%	0%	<1%	1%	0%
Moderately high soil vulnerability potential	3%	<1%	0%	16%	0%	16%	0%
Moderate soil vulnerability potential	6%	12%	0%	21%	0%	10%	0%
Low soil vulnerability potential	91%	87%	99%	62%	100%	72%	100%

Note: Percents may not add to 100 within categories due to rounding.

Table B4. Percent of cropped acres within basins for conservation treatment needs, by basin, in the Great Lakes Region

Category	Great Lakes Region	Western Lake Michigan	Eastern Lake Michigan	Lake Huron	Western Lake Erie subregion (code 0410)	Other Lake Erie, subregions (codes 0409, 0411, and 0412)	Lake Ontario
Percent of cropped acres within basin with conservation treatment needs for sediment loss							
High level of treatment need	4%	6%	4%	1%	2%	6%	11%
Moderate level of treatment need	2%	5%	3%	0%	1%	2%	5%
Percent of cropped acres within basin with conservation treatment needs for nitrogen lost with runoff							
High level of treatment need	0%	0%	0%	0%	0%	0%	0%
Moderate level of treatment need	6%	11%	7%	1%	2%	8%	16%
Percent of cropped acres within basin with conservation treatment needs for phosphorus lost to surface water							
High level of treatment need	0%	0%	0%	0%	0%	0%	0%
Moderate level of treatment need	12%	20%	10%	10%	4%	18%	28%
Percent of cropped acres within basin with conservation treatment needs for nitrogen loss in subsurface flows							
High level of treatment need	16%	22%	22%	23%	6%	5%	22%
Moderate level of treatment need	29%	18%	26%	26%	40%	21%	30%
Percent of cropped acres within basin with conservation treatment needs for wind erosion							
High level of treatment need	0%	0%	0%	0%	0%	0%	0%
Moderate level of treatment need	2%	1%	0%	8%	<1%	9%	0%
Percent of cropped acres within basin with conservation treatment needs for one or more resource concern							
High level of treatment need	19%	26%	25%	24%	8%	11%	32%
Moderate level of treatment need	34%	28%	28%	32%	40%	36%	39%
Under-treated (high or moderate level of treatment need)	53%	54%	54%	56%	48%	46%	71%