



National Water-Quality Assessment Program

County-Level Estimates of Nutrient Inputs to the Land Surface of the Conterminous United States, 1982–2001

Scientific Investigations Report 2006–5012

**U.S. Department of the Interior
U.S. Geological Survey**

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By Barbara C. Ruddy, David L. Lorenz, and David K. Mueller

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Foreword

The U.S. Geological Survey (USGS) is committed to providing the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life and that facilitates effective management of water, biological, energy, and mineral resources (<http://www.usgs.gov/>). Information on the quality of the Nation's water resources is critical to assuring the long-term availability of water that is safe for drinking and recreation and suitable for industry, irrigation, and habitat for fish and wildlife. Population growth and increasing demands for multiple water uses make water availability, now measured in terms of quantity and quality, even more essential to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program in 1991 to support national, regional, and local information needs and decisions related to water-quality management and policy (<http://water.usgs.gov/nawqa>). Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities.

From 1991 to 2001, the NAWQA Program completed interdisciplinary assessments in 51 of the Nation's major river basins and aquifer systems, referred to as "Study Units" (<http://water.usgs.gov/nawqa/studyu.html>). Baseline conditions were established for comparison to future assessments, and long-term monitoring was initiated in many of the basins. During the next decade, 42 of the 51 Study Units will be reassessed so that 10 years of comparable monitoring data will be available to determine trends at many of the Nation's streams and aquifers. The next 10 years of study also will fill in critical gaps in characterizing water-quality conditions, enhance understanding of factors that affect water quality, and establish links between sources of contaminants, the transport of those contaminants through the hydrologic system, and the potential effects of contaminants on humans and aquatic ecosystems.

The USGS aims to disseminate credible, timely, and relevant science information to inform practical and effective water-resource management and strategies that protect and restore water quality. We hope this NAWQA publication will provide you with insights and information to meet your needs, and will foster increased citizen awareness and involvement in the protection and restoration of our Nation's waters.

The USGS recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The NAWQA Program, therefore, depends on advice and information from other agencies—Federal, State, interstate, Tribal, and local—as well as nongovernmental organizations, industry, academia, and other stakeholder groups. Your assistance and suggestions are greatly appreciated.

Robert M. Hirsch
Associate Director for Water

Contents

Foreword	iii
Abstract	1
Introduction.....	1
Purpose and Scope	1
Acknowledgments	3
Data Sources	3
Association of American Plant Food Control Officials	3
Census of Agriculture.....	4
U.S. Census Bureau.....	4
National Atmospheric Deposition Program	4
Estimation of County-Level Nutrient Inputs.....	4
Nutrient Inputs from Fertilizer Use.....	4
Nutrient Inputs from Livestock Manure	6
Nutrient Inputs from Atmospheric Deposition	8
Description of the County-Level Nutrient-Input Dataset	8
Spatial and Temporal Patterns in Nutrient Inputs	9
Allocation of Nutrient Inputs to Specific Land Uses.....	9
Spatial Distribution of Nutrient Inputs.....	10
Temporal Changes in Nutrient Inputs.....	12
Summary.....	16
References Cited.....	16

Figures

1. Map showing the location of NAWQA study units investigated during 1991 through 2001	2
2. Graph showing the relation between population density and nonfarm-fertilizer sales, by county, 1992.....	6
3-6. Maps showing:	
3. Nitrogen input from farm fertilizer, in 1997, allocated to agricultural land within a county.....	10
4. Nitrogen input from nonfarm fertilizer, in 1997, allocated to selected urban land within a county	11
5. Nitrogen input from livestock manure, in 1997, allocated to agricultural land and grasslands within a county.....	11
6. Nitrogen input from atmospheric deposition for 1997	12
7. Graph showing annual nutrient inputs to the conterminous United States, 1945–2001	13

8–10. Maps showing:

8. Percent change between 1987 and 1997 in nitrogen input from farm fertilizer allocated to agricultural land within a county14
9. Percent change between 1987 and 1997 in nitrogen input from nonfarm fertilizer allocated to selected urban land within a county15
10. Percent change between 1987 and 1997 in nitrogen input from livestock manure allocated to agricultural land and grasslands within a county.....15

Tables

1. Data sources used for nutrient estimates3
2. Determination of populations for livestock groups used to evaluate manure inputs based on categories reported by the Census of Agriculture7
3. Estimates of the nitrogen and phosphorus content in livestock manure8
4. Land-cover classifications used for allocation of fertilizer and manure inputs within a county9
5. Nitrogen and phosphorus inputs in the conterminous United States for 1987 and 1997.....13

Conversion Factors

Multiply	By	To obtain
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
square kilometer (km ²)	0.3861	square mile (mi ²)
kilogram (kg)	2.205	pound avoirdupois (lb)
metric ton	1.102	ton, short (2,000 lb)
kilograms per hectare (kg/ha)	0.8921	pounds per acre (lb/acre)
kilogram per square kilometer (kg/ km ²)	0.008921	pound per acre (lb/acre)

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Abbreviations and Acronyms

AAPFCO	Association of American Plant Food Control Officials
FIPS	Federal Information Processing Standards
GIS	geographic information system
LOWESS	Locally Weighted Scatterplot Smoothing
LULC	land use and land cover
NADP	National Atmospheric Deposition Program
NAWQA	National Water-Quality Assessment
NLCD-92	National Land Cover Data 1992
NLCDe92	enhanced version of NLCD-92
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

County-Level Estimates of Nutrient Inputs to the Land Surface of the Conterminous United States, 1982–2001

By Barbara C. Ruddy, David L. Lorenz, and David K. Mueller

Abstract

Nutrient input data for fertilizer use, livestock manure, and atmospheric deposition from various sources were estimated and allocated to counties in the conterminous United States for the years 1982 through 2001. These nationally consistent nutrient input data are needed by the National Water-Quality Assessment Program for investigations of stream- and ground-water quality. For nitrogen, the largest source was farm fertilizer; for phosphorus, the largest sources were farm fertilizer and livestock manure. Nutrient inputs from fertilizer use in nonfarm areas, while locally important, were an order of magnitude smaller than inputs from other sources. Nutrient inputs from all sources increased between 1987 and 1997, but the relative proportions of nutrients from each source were constant. Farm-fertilizer inputs were highest in the upper Midwest, along eastern coastal areas, and in irrigated areas of the West. Nonfarm-fertilizer use was similar in major metropolitan areas throughout the Nation, but was more extensive in the more populated Eastern and Central States and in California. Areas of greater manure inputs were located throughout the South-central and Southeastern States and in scattered areas of the West. Nitrogen deposition from the atmosphere generally increased from west to east and is related to the location of major sources and the effects of precipitation and prevailing winds. These nutrient-loading data at the county level are expected to be the fundamental basis for national and regional assessments of water quality for the National Water-Quality Assessment Program and other large-scale programs.

Introduction

Elevated nutrient concentrations are a leading cause of contamination in streams, lakes, wetlands, estuaries, and ground water of the United States (U.S. Environmental Protection Agency, 2002a). Nutrients are chemical elements that are essential to plant and animal nutrition, but in high concentrations they can be contaminants in water. Nutrients occur as various chemical compounds, predominantly containing nitrogen or phosphorus.

Evaluation of nutrient contamination in streams and ground water is a primary objective of the U.S. Geologi-

cal Survey (USGS) National Water-Quality Assessment (NAWQA) Program. This program was designed to assess the status of, and trends in, the quality of the Nation's streams and ground water and to link the status and trends with an understanding of the natural and anthropogenic factors that affect the quality of water (Hirsch and others, 1988; Leahy and Thompson, 1994; Gilliom and others, 1995). The NAWQA Program investigates water quality in 52 major river basins and associated aquifers, which are referred to as "study units" (fig. 1). Implementation of these investigations is phased so that high-intensity sampling occurs in about one-third of the study units at a time. Investigations in the first 20 study units began in 1991, and sampling occurred during 1993–95. A second group of 16 study units was started in 1994, with most of the sampling completed during 1996–98. A third group consisting of 16 study units began in 1997 with most of the data collected during 1999–2001.

Information on nutrient sources is important in understanding the variability of nutrient concentrations in streams and ground water over time and space, which is a goal of the NAWQA Program. Nonpoint sources of nutrients include fertilizer use, livestock manure, and atmospheric deposition. Application of commercially produced fertilizer is a major source of nitrogen and phosphorus input. Fertilizers are used to increase crop production in agricultural areas and to keep lawns, parks, and fairways green in urban and suburban areas. Livestock manure can be a substantial source of nitrogen and phosphorus to the land in agricultural areas. Manure often is spread on cropland, but also can accumulate in pastures and other areas where livestock graze. Deposition from the atmosphere is an additional source of the nitrogen to the Earth's surface. Nitrogen oxide emissions from fossil fuel combustion and ammonia emissions from agricultural activities are major contributors to atmospheric sources of nitrogen (U.S. Environmental Protection Agency, 2002b).

Purpose and Scope

This report presents estimates of nitrogen and phosphorus inputs to the land surface in counties of the conterminous United States during 1982 through 2001. The purpose is to consolidate data on nutrient inputs from fertilizer use, livestock manure, and atmospheric deposition and make them

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM – CYCLE 1

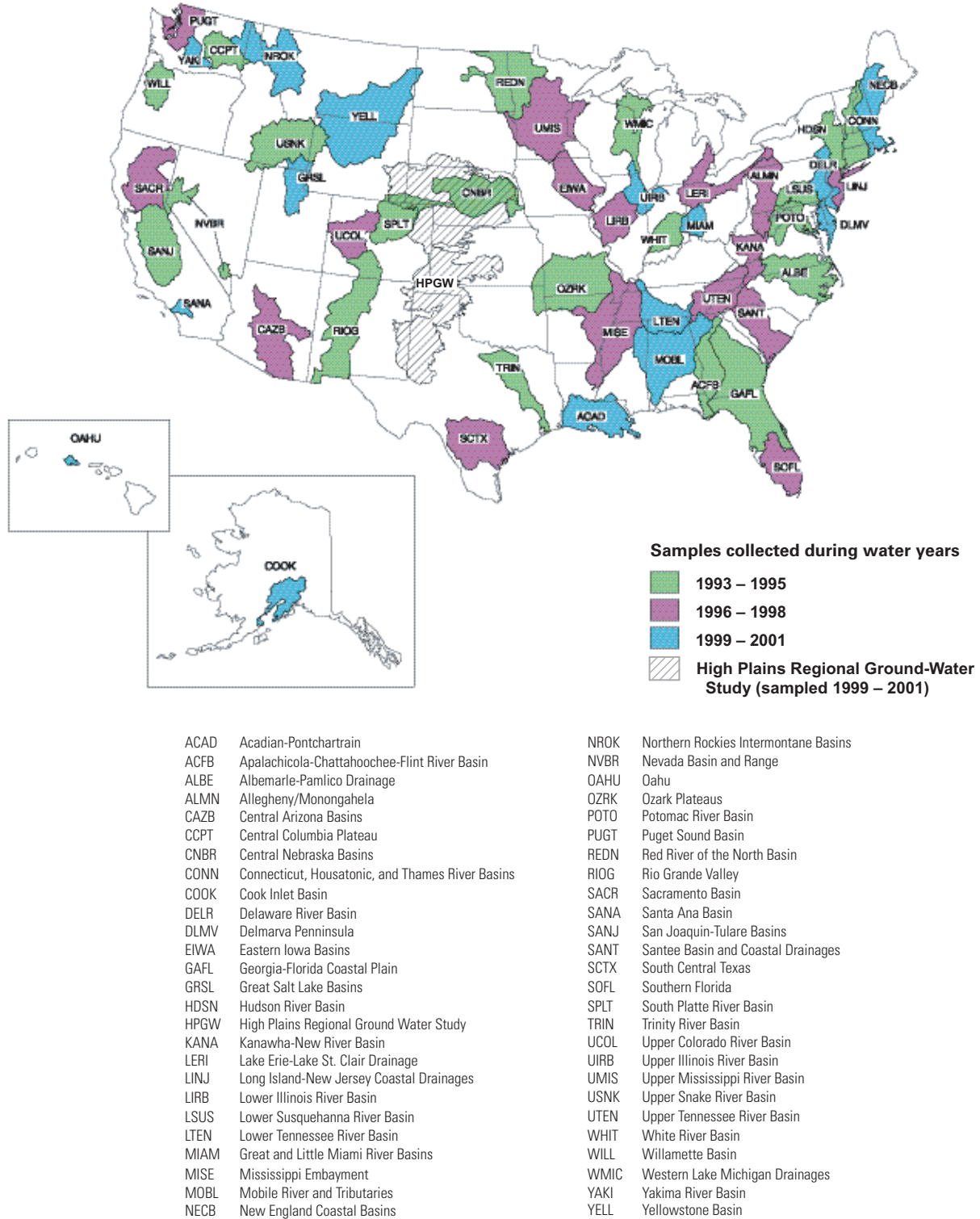


Figure 1. Location of NAWQA study units investigated during 1991 through 2001.

available in a consistent format. Methods are described for allocating data on State total fertilizer sales to individual counties, for estimating manure generation from livestock populations, and for interpolating deposition of atmospheric nitrogen. Annual inputs of nitrogen and phosphorus from fertilizer use are estimated for 1987 through 2001; inputs of nitrogen and phosphorus from livestock manure are estimated for 1982, 1987, 1992, and 1997; and nitrogen inputs from atmospheric deposition are estimated for 1985 through 2001. Estimates from all sources are provided by county for the conterminous United States. In addition, estimates are mapped to show the spatial distribution of nutrient inputs in 1997 and the change in inputs between 1987 and 1997.

Acknowledgments

The authors thank Bob Larson of the Illinois State Water Survey for contributing information about the allocation of atmospheric deposition of nutrients; David Terry, of the Association of American Plant Food Control Officials, for providing the fertilizer data, including missing historical data; Robert Kellogg of the Natural Resources Conservation Service for advice on manure allocation; Yvonne Baevsky of the USGS for her annual summaries of atmospheric deposition; and JoAnn Gronberg, Kerie Hitt, Naomi Nakagaki, Curtis Price, Norm Spahr, and David Wolock of the USGS for assistance with data processing.

Data Sources

Table 1 lists the sources and time periods of data used in this report to estimate nutrient inputs by county. Each of these data sources is described in the following sections.

Association of American Plant Food Control Officials

Data on the annual sales of commercially produced fertilizer are compiled by the Association of American Plant Food Control Officials (AAPFCO) at the University of Kentucky. These data are collected, according to uniform reporting requirements, by regulatory agencies in each State. Before 1985, State fertilizer-sales data were compiled by the U.S. Department of Agriculture (USDA).

Gaither and Terry (2004) provide a detailed description of the AAPFCO data. Each State is required to provide annual data on the sales of commercial fertilizer products. For many States, these data include sales of products used in nonfarm areas as well as those used on farms because licensed distributors are required to report sales of all fertilizer products to State regulators. About one-half of the States distinguish between products sold for farm use and those sold for nonfarm use. Most States report fertilizer sales on the basis of the fertilizer year, which ends on June 30. For example, fertilizer sales reported for 1995 span the period of July 1, 1994, through June 30, 1995. Three States use different reporting periods. Texas reports data for sales during September 1 through August 31; thus, for example, fertilizer sales reported for 1995 span the period of September 1, 1994, through August 31, 1995. North Dakota and South Dakota report data for the previous calendar year; thus, for example, their reports for 1995 include sales made during January 1, 1994, through December 31, 1994.

Annual State data compiled by AAPFCO include sales of individual fertilizer products (in tons), a fertilizer code for each product, an optional use code (farm or nonfarm), and the chemical composition of each fertilizer product in terms of nitrogen (N), phosphate (P_2O_5), and potash (K_2O). If sales data submitted by a State are incomplete for any year, AAPFCO estimates the total annual sales of a product by using data from the previous year, as well as any monthly data that are available for the current year. Most States collect and report

Table 1. Data sources used for nutrient estimates.

Source	Data	Time period	Scale
Association of American Plant Food Control Officials	Fertilizer sales	Annually, 1987 through 2001	State and county
Census of Agriculture	Expenditures on fertilizer; Livestock populations	1982, 1987, 1992, 1997, and 2002	State and county
U.S. Census Bureau	Human population	1990 and 2000 (actual); 1987–89, 1991–99, and 2001 (estimated)	County
National Atmospheric Deposition Program	Wet deposition chemistry	Annually, 1985 through 2001	Point locations

4 County-Level Estimates of Nutrient Inputs to the Land Surface of the Conterminous United States, 1982–2001

the sales data by county. Sales data reported by county are not considered reliable for estimating the spatial distribution of fertilizer use because multicounty distributors can report their total sales for a single county rather than for individual counties. Also, farmers can use fertilizer in a different county from where it was sold. Because of these uncertainties, AAPFCO data used in this report were aggregated to State total sales of each product.

Census of Agriculture

Data on the Nation's agricultural production are collected at 5-year intervals by the Census of Agriculture. Farms with more than \$1,000 in agricultural-product sales are requested to report statistics on their farming operations. Congress uses these statistics in developing and evaluating the effectiveness of farm programs. The U.S. Census Bureau conducted the Census of Agriculture through 1992. In 1997, the USDA assumed this responsibility. The most recent data used in this report are described by the U.S. Department of Agriculture (2004).

Calendar-year fertilizer expenditures and populations of selected livestock within each county were obtained from the Census of Agriculture for 1982, 1987, 1992, 1997, and 2002. The 2002 data were used in this report only to estimate values for 1998–2001 by interpolation with 1997 data. Calendar-year expenditures on fertilizer were used to allocate State farm-fertilizer sales, reported by AAPFCO, to individual counties. Data on calendar year-end populations of selected livestock within each county were used to estimate nutrient inputs from manure. Complete data for some counties are not reported because of Census of Agriculture rules stating that no data can be published that would disclose the operations of an individual farm.

U.S. Census Bureau

Human population data for 1990 and 2000 and population estimates for 1987–89, 1991–99, and 2001 were obtained from the U.S. Census Bureau. All population data were available by county for each State. These population data and estimates were used to allocate State nonfarm-fertilizer sales, reported by AAPFCO, to individual counties.

National Atmospheric Deposition Program

Data on deposition of nitrogen from the atmosphere are collected by the National Atmospheric Deposition Program (NADP). The NADP sampling network is a cooperative effort among State Agricultural Experiment Stations, the USGS, the USDA, and numerous other governmental and private entities. The primary purpose of this network is to provide information on geographical and temporal trends in the chemistry of precipitation.

Annual data on wet deposition of nitrogen were obtained for 177 to 225 NADP sampling sites, depending on the year, in the conterminous United States. Precipitation samples are collected weekly at each station, using rigorous protocols to maintain sample integrity. The samples are analyzed for nitrate, ammonium, and other constituents at the NADP Central Analytical Laboratory, operated by the Illinois State Water Survey in Champaign, Illinois. Phosphorus compounds are not included because concentrations generally are not significant and samples are subject to contamination. Specific quality-assurance criteria must be met in order for a sample to be used in deposition summary statistics. The NADP provides summary data in a series of annual reports (for example, National Atmospheric Deposition Program, 2002), which are available online at <http://nadp.sws.uiuc.edu/>.

Estimation of County-Level Nutrient Inputs

Methods for estimating annual nutrient inputs by county are described in the following sections. Separate methods are described for estimating inputs to the land surface from fertilizer use, livestock manure, and atmospheric deposition. These estimates can then be summed to determine total nitrogen and phosphorus inputs for each county.

Nutrient Inputs from Fertilizer Use

Historically, several methods have been used to allocate State fertilizer data to counties. Alexander and Smith (1990) obtained annual State fertilizer-sales data, in tons, compiled by USDA for 1945 through 1985. They used county fertilized-acreage data from the Census of Agriculture to allocate the State-level fertilizer sales to nutrient input from fertilizer use within individual counties. The term “fertilizer use,” in this context, refers to the mass nutrients (nitrogen or phosphorus) applied to land within a county. All fertilizer sold in a year was assumed to be applied in that same year. Fertilizer-sales data were converted from tons of product to tons of nitrogen and phosphorus, based on the chemical composition data for each product. Battaglin and Goolsby (1995) reported estimates of county-level fertilizer use for 1985 through 1991. These estimates were calculated from annual State fertilizer sales compiled by the National Fertilizer and Environmental Research Center at the Tennessee Valley Authority. Calculations were based on a computer program developed by Jerald Fletcher (West Virginia University, written commun., 1992). State sales were allocated to individual counties on the basis of county fertilizer-expenditure data from the 1987 Census of Agriculture:

$$FCU_{ik} = FSS_i \left(\frac{FCE_{ik}}{FSE_i} \right) \quad (1)$$

where

FCU_{ik} is the estimated annual nutrient input from use of commercial fertilizer in county k of State i , in tons of nitrogen or phosphorus;
 FSS_i is the total fertilizer sales for State i , in tons of nitrogen or phosphorus;
 FCE_{ik} is the fertilizer expenditures in 1987 for county k of State i , in dollars; and
 FSE_i is the total 1987 fertilizer expenditures for State i , in dollars.

County-level fertilizer expenditures are based on the residence of the purchaser and thus are different from county-level fertilizer sales, which are based on the location of the seller.

In this report, county-level expenditures from the Census of Agriculture also were used to allocate State-level fertilizer sales data from AAPFCO; however, separate allocation methods were used for fertilizers applied on farms and for those applied in nonfarm areas. Because farm- and nonfarm-fertilizer sales are differentiated by only about 40–50 percent of States in any specific year, a procedure was developed to estimate nonfarm-fertilizer sales for all States. For each year, data were selected for all fertilizer products that had reported nonfarm sales in States that reported nonfarm sales for at least 11 products. This criterion was applied to eliminate States with limited or erroneous data on nonfarm sales. Using the selected data, national totals of farm and nonfarm sales were computed for each fertilizer product in each year. These totals were then converted to proportions, which were applied to the annual sales of each fertilizer product to estimate farm and nonfarm sales within each State.

The first step in calculating nutrient inputs was to convert the AAPFCO fertilizer-sales data from tons of product to kilograms of nitrogen and phosphorus, based on the chemical composition data for each product. If compositions were not specified for a product by a State, default percentages based on the product's fertilizer code were used. This initial processing identified questionable data, such as specified nitrogen compositions greater than 100 percent or fertilizer products without any available chemical composition data. These questionable data were removed from subsequent analysis. Furthermore, the maximum value for nitrogen composition was set at 50 percent, except for anhydrous ammonia (82 percent), and the maximum value for phosphate composition was set at 75 percent.

Annual sales data for each nutrient (nitrogen and phosphorus) in each fertilizer category (farm and nonfarm) were summed for each State. County-level nutrient inputs from farm-fertilizer use were estimated to be in proportion to fertilizer expenditures in each county:

$$FFCU_{ik} = FFSS_i \left(\frac{FCE_{ik}}{FSE_i} \right) \quad (2)$$

where

$FFCU_{ik}$ is the estimated nutrient input from farm-fertilizer use in county k of State i , in kilograms of nitrogen or phosphorus;
 $FFSS_i$ is total farm-fertilizer sales for State i , in kilograms of nitrogen or phosphorus;
 FCE_{ik} is fertilizer expenditures for county k of State i , in dollars; and
 FSE_i is total fertilizer expenditures for State i , in dollars.

Fertilizer expenditure data were obtained from the Census of Agriculture; therefore, they were available only every 5 years. For the intervening years, State and county fertilizer expenditures (FSE_i and FCE_{ik}) were estimated by linear interpolation. In cases where fertilizer expenditures were not disclosed for a county in a particular Census of Agriculture year, the interpolation was done between the nearest census years that had disclosed values. If nondisclosed values occurred at either end of the time period, the nearest disclosed value was used for all previous or subsequent years.

State sales of nonfarm fertilizer were allocated to the county level by using population data. Nonfarm-fertilizer sales in 1992 show an approximately linear relation with population density on a log-log plot (fig. 2). A LOWESS smooth (Cleveland, 1979) fit to these data reveals this relation has a fairly constant slope of 1.3 up to a population density of about 700 people per square kilometer, above which there is little or no increase in fertilizer sales. The pattern is similar for plots of both nitrogen and phosphorus in nonfarm-fertilizer sales during 1992 and 1997. The observed relation was accommodated by defining the "effective population" of a county, based on the generalizations that nonfarm-fertilizer sales are proportional to population density raised to the 1.3 power up to a population density of 700 people per square kilometer, and that sales do not increase with further increases in population density. It is likely that fertilizer use decreases at very high population densities, but data were insufficient to model such a decrease. The equation for the effective population is:

$$EPC_{ik} = A_{ik} \times \text{minimum} (P_{ik}, 700)^{1.3} \quad (3)$$

where

EPC_{ik} is the effective population of county k in State i ;
 A_{ik} is the area of county k in State i , in square kilometers; and
 P_{ik} is the population density of county k in State i , in people per square kilometer.

County-level nutrients from nonfarm-fertilizer use were then estimated to be in proportion to effective population in each county:

$$NFCU_{ik} = NFSS_i \left(\frac{EPC_{ik}}{EPS_i} \right) \quad (4)$$

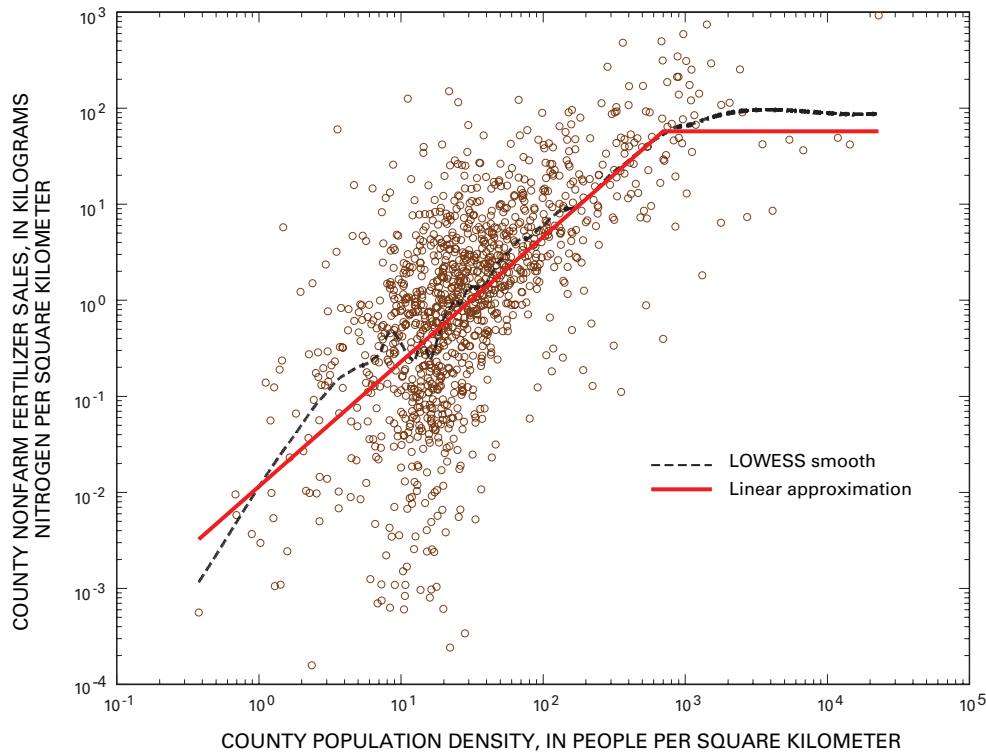


Figure 2. Relation between population density and nonfarm-fertilizer sales, by county, 1992.

where

$NFCU_{ik}$ is the estimated nutrient inputs from nonfarm-fertilizer use in county k of State i , in kilograms of nitrogen or phosphorus;

$NFSS_i$ is total nonfarm-fertilizer sales for State i , in kilograms of nitrogen or phosphorus; and

EPS_i is the sum of EPC_{ik} for State i .

Where farm- and nonfarm-use codes are present, they are considered reasonably accurate by the State regulators (Robert Hopkins, Maryland Department of Agriculture, oral commun., 1999, and Dan Schweitzer, Virginia Department of Agriculture and Consumer Services, oral commun., 1999). Inspection of the AAPFCO data indicates that most fertilizer products used on grass and lawns are coded as “nonfarm” use and that few products used on crops are coded as “nonfarm.” During several years, two States made changes in the way fertilizer products were categorized in their reports to AAPFCO. These changes involved aggregation of the sales of several fertilizer products into a single reported value. The affected data are for 1996 through 2001 for Colorado and 1997 through 2001 for Washington. For these years, the estimated nonfarm-fertilizer use might be low because the aggregated sales were not included in allocation of products to farm and nonfarm uses.

Nutrient Inputs from Livestock Manure

Estimates of nutrient inputs from manure were based on county-level livestock population data collected by the Census of Agriculture. The method and assumptions described by Goolsby and others (1999) were used to estimate the nitrogen and phosphorus content of manure produced by various types of livestock. This method takes into account differences in the life cycles of farm animals during the year and for nutrient losses in storage, handling, and application of manure. An animal life cycle is the time from birth to slaughter. Estimates of nutrient input were made separately for each livestock group and then summed by county.

The livestock groups used in this report to estimate nutrient inputs from manure are listed in table 2, along with the Census of Agriculture animal categories used to determine populations of these groups. Because of Census of Agriculture regulations, data that would disclose operations of an individual farm are not published. For counties that have only one farm operation for a specific category of livestock, the population of that category is reported as “nondisclosed.” Table 2 lists the computations used to estimate livestock-group populations if the primary category was reported as nondisclosed. In some cases, the secondary categories used in these computations also were reported as nondisclosed, and the population of the livestock group could not be determined. In general, total populations of cattle, hogs, or poultry were completely nondisclosed for less than 1 percent of all counties; however,

Table 2. Determination of populations for livestock groups used to evaluate manure inputs based on categories reported by the Census of Agriculture [U.S. Department of Agriculture, 2004].

[--, not applicable]

Livestock group in this report	Primary category from Census of Agriculture	Computation used if primary category population was not disclosed
Milk cows	Milk cows	0.5 x All heifers and calves
Beef cattle	Beef cows	0.5 x All heifers and calves
Steers	0.5 x Steers	0.5 x (0.5 x (Total cattle - (Milk cows + Beef cattle))
Heifers	0.5 x Heifers	0.5 x (0.5 x (Total cattle - (Milk cows + Beef cattle))
Slaughter cattle	0.5 x (Heifers + Steers)	--
Hogs and pigs	Hogs and pigs	Hogs for breeding + Other hogs, or 0.5 x Hogs sold except feeder pigs
Chickens and hens	Layers more than 20 weeks old	Layers and pullets more than 13 weeks old
Pullets and broilers	Pullets 13-20 weeks old + Pullets less than 13 weeks old + Broilers	--
Tom turkeys	0.5 x Turkeys	--
Hen turkeys	0.5 x Turkeys + Hen turkeys kept for breeding	--
Sheep and lambs	Sheep and lambs	--
Horses and ponies	Horses and ponies	--

hog population could not be determined for about 3 percent of counties in 1987 and 1992 and about 8 percent of counties in 1997. Similarly, total poultry populations could not be determined for about 8 percent of counties in 1997. The USDA has access to unpublished data for these nondisclosed livestock populations. Kellogg and others (2000) used these data by merging up to 11 adjacent counties to prevent disclosure of data for individual farms. The merged data provide more accurate State total populations but less accurate information on the distribution of livestock among counties. Also, the merged data did not include sheep and lamb or horse and pony populations. For the purposes of nutrient-input estimation in this report, it was determined that retaining the spatial information contained in the county-level data was more important than including all the nondisclosed animal counts.

The factors used to estimate the nitrogen and phosphorus content of livestock manure are listed in table 3. The total mass of nutrients in manure from a livestock group was calculated as the product of the population, the nutrient content of manure, and the number of days in the life cycle. For example, nitrogen input in a county with 100 milk cows would be:

$$\text{Nitrogen input} = 100 \text{ animals} \times 0.204 \text{ kg/day per animal} \times 365 \text{ days} = 7,446 \text{ kg.}$$

The nutrient content of hog and pig manure is based on animal weight, but because the Census of Agriculture does not report hogs and pigs by weight class, factors for the average weight class (60–119 pounds) were applied to the total population.

Livestock populations are reported in the Census of Agriculture as calendar year-end inventory numbers. For most livestock groups, the year-end inventory was assumed to be representative of the population throughout the year. This includes livestock such as hogs, chickens, and sheep that have life spans of less than one year but are subject to multiple annual marketings. Nutrient inputs from a few livestock groups were estimated for only a portion of a year. Many steers and heifers are slaughtered in their first year; therefore, slaughter cattle (50 percent of the reported steer and heifer inventories) were assumed to live 170 days. Tom turkeys were assumed to live 133 days, and hens, except those kept for breeding, were assumed to live 112 days.

Total manure inputs of nitrogen and phosphorus were calculated by summing the estimates for each livestock group for each county and each year in which a Census of Agriculture was reported (1982, 1987, 1992, and 1997). Each county total was divided into (1) a component of animals raised in confined feeding operations and (2) a component of those that were not confined. Ratios of manure production from confined and unconfined livestock were determined on the basis of data reported by Kellogg and others (2000). Separate ratios were determined for nitrogen and phosphorus, for each county and for each year.

Nitrogen in manure can be lost to the atmosphere due to volatilization during storage and application. The extent of loss depends on manure type, storage and handling, and field application methods (Burkart and James, 1999). In this report, loss through volatilization was considered in determin-

Table 3. Estimates of the nitrogen and phosphorus content in livestock manure (modified from Goolsby and others, 1999).

Livestock group	Nutrient content of manure (kilograms per day per animal)		Life cycle (number of days)
	Nitrogen	Phosphorus	
Milk cows	0.204	0.032	365
Beef cattle	0.150	0.053	365
Steers	0.150	0.048	365
Heifers	0.141	0.018	365
Slaughter cattle	0.104	0.034	170
Hogs and pigs ¹	0.027	0.012	365
Chickens and hens ¹	0.0015	0.0006	365
Pullets and broilers ¹	0.0010	0.0003	365
Tom turkeys	0.0054	0.0020	133
Hen turkeys	0.0034	0.0013	112 or 365
Sheep and lambs ¹	0.023	0.004	365
Horses and ponies	0.127	0.022	365

¹ Animals in these groups have a life cycle shorter than one year, but year-end inventories are assumed representative of year-round population.

ing the nitrogen content of manure from each livestock group. Subsequent deposition of volatilized nitrogen is included in measurements of inputs from the atmosphere, described in the next section of this report.

Nutrient Inputs from Atmospheric Deposition

Annual summaries of wet deposition of nitrate and ammonium, in kilograms per hectare, were obtained from the NADP Web page (<http://nadp.sws.uiuc.edu/>). These data were processed as follows, in order to estimate atmospheric deposition of inorganic nitrogen by county:

1. The point location of the collection sites and the data values were obtained from the NADP Web page.
2. Geographic information system (GIS) point datasets of the sampling locations were created for each of the years that data were retrieved. Separate datasets were made for each year because the number and location of collection sites varied during the time period.
3. Estimated deposition rates for total nitrogen (nitrate plus ammonium) in 1-km-resolution grid cells were derived from each of the point coverages using GIS inverse distance-weighted interpolation with a power of 3.
4. Annual deposition values by county were obtained by calculating the mean deposition rate for grid cells within the county boundary.

5. The county deposition rates were multiplied by the county area to obtain the mass nitrogen deposition in kilograms.

The number of sites used in the analyses ranged from a low of 177 in 1985 to a high of 225 in 2001 and was about 190 for most years. Interpolation of nitrogen deposition is better for years with data from a greater number of sites.

Description of the County-Level Nutrient-Input Dataset

The nutrient-input data described in this report are in a data set that is available online at http://water.usgs.gov/pubs/sir/2006/5012/excel/Nutrient_Inputs_1982-2001jan06.xls. This data set contains estimates of nitrogen (as N) and phosphorus (as P) inputs, expressed in kilograms, for each county in the conterminous United States. Separate estimates are listed for farm and nonfarm fertilizer use, livestock manure, and atmospheric deposition. Fertilizer use estimates are provided annually for 1987 through 2001 and are subdivided into farm and nonfarm inputs. Livestock manure estimates are provided for Census of Agriculture years (1982, 1987, 1992, and 1997) and are subdivided into inputs from confined and unconfined livestock. Estimates of nitrogen in atmospheric deposition are provided annually for 1985 through 2001. Counties are identified by State, county, and Federal Information Processing System (FIPS) code. The data are sorted alphabetically by State, and numerically by FIPS code within each State. The area (in square kilometers) is listed for each county. For consistency and ease in reporting, county boundaries were kept the same throughout the period of

record presented in this data set, even though several changes occurred. For example, South Boston City, VA (FIPS 51780) was merged into Halifax County, VA (FIPS 51083) in 1995, but nutrient inputs in this data set are presented separately for South Boston City through 2001. Although its boundaries did not change, Dade County, FL (FIPS 12025) was renamed Miami-Dade County in 1997 and assigned a new FIPS code (12086). In this data set, the new name and FIPS code are used throughout the time period (1982–2001).

Spatial and Temporal Patterns in Nutrient Inputs

Nitrogen inputs from fertilizer use, livestock manure, and atmospheric deposition for the conterminous United States in 1997 were mapped to show the spatial distribution of the inputs and where each type of input was more prevalent. Nitrogen and phosphorus inputs from various sources for 1945–2001 were graphed to show the changes in nutrient inputs at a national scale. The percent change in each type of nitrogen input between 1987 and 1997 was mapped in order to indicate changes over time.

Allocation of Nutrient Inputs to Specific Land Uses

For spatial analysis, county-level estimates of nitrogen inputs from fertilizer and livestock manure were mapped to

specific land uses within each county. Land use was determined from a USGS land-use/land-cover dataset. This dataset is based on the 1992 National Land Cover Data (NLCD–92), a 30-m resolution raster (grid) dataset classifying land cover of the conterminous United States in the early to mid-1990s (Vogelmann and others, 2001). Classifications of land cover in some NLCD–92 grid cells were modified for consistency with the USGS Land Use and Land Cover (LULC) dataset, which is based on aerial photography taken in the 1970s to mid-1980s (U.S. Geological Survey, 1990). The LULC dataset provides better classification for certain types of land cover than the NLCD–92 dataset that are difficult to interpret from satellite imagery. Modifications to the NLCD–92 dataset are described by Nakagaki and Wolock (2005); the revised dataset is referred to as “the enhanced National Land Cover Data (NLCDe92)”.

Nitrogen inputs from fertilizer and manure were allocated to various NLCDe92 land-cover classes within each county as shown in table 4. Nitrogen input from atmospheric deposition was allocated to all land-cover classes. For each type of input, the estimated nitrogen mass was divided by the total area of allocated land cover in order to determine an input application rate. For display in the following figures, nitrogen input rates from the NLCDe92 30-m dataset were mapped to the NLCDe92 1-km dataset because the 30-m resolution was too small for page-size national maps. Where possible, the same application rate categories were used in all figures in order to facilitate visual comparisons of the differences in rates among nutrient sources.

Table 4. Land-cover classifications used for allocation of fertilizer and manure inputs within a county.

[LULC, Land Use and Land Cover dataset; NLCD, National Land Cover Data; *, revised classification in the NLCDe92 dataset; --, not applicable]

NLCDe92 land-cover classification (from Nakagaki and Wolock, 2005)	Nutrient input category			
	Farm fertilizer	Nonfarm fertilizer	Manure from confined animals	Manure from unconfined animals
Agricultural land				
Orchards/vineyards/other	X	--	--	--
LULC orchards/vineyards/other*	X	--	--	--
Pasture/hay	X	--	X	X
Row crops	X	--	X	X
Small grains	X	--	X	X
Fallow	X	--	X	X
Grasslands/herbaceous	--	--	--	X
Urban land				
Low intensity residential	--	X	--	--
LULC residential*	--	X	--	--
NLCD/LULC forested residential*	--	X	--	--
Urban/recreational grasses	--	X	--	--

Spatial Distribution of Nutrient Inputs

Patterns of nitrogen input from farm fertilizer applied to agricultural land for 1997 are shown in figure 3. In general, areas of high application rates are in the upper Midwest and along the east coast, and the extensive agricultural areas in the eastern two-thirds of the United States show a large range of application rates. Large parts of the West are not used for agriculture, but application rates are high in the intensively irrigated areas of southern Idaho, eastern Washington, northwestern Oregon, and central California.

Figure 4 shows the patterns of nitrogen input from non-farm-fertilizer application during 1997. Application rates were similar in major metropolitan areas throughout the Nation, but input was more extensive in the more populated Eastern and Central States and in California. Generally, rates were highest toward the center of a metropolitan area and lower in the outlying suburbs. Many small towns are evident, usually with low application rates; although some of the smallest residential areas might not appear at the 1-km grid scale of this map. Nonfarm application rates in Ohio and Georgia appear lower than the surrounding States, but these differences probably were due to differences among States in the way fertilizer products are coded in sales reports. If sales are not coded to

a product that has a nonfarm use, then nonfarm input will be underestimated. Although not as obvious on the map, similar reporting issues might affect estimated application rates in Colorado and Washington.

The allocation of nitrogen input from livestock manure for 1997 is shown in figure 5. Regionally, input rates were highest in the South-Central and Southeastern United States where the livestock populations are high. Throughout many parts of the Western States, livestock populations are more dispersed on extensive grassland areas, resulting in lower nitrogen input rates. In parts of the West, such as the dairy-farming areas of California, nitrogen input rates were high due to a relatively high concentration of livestock.

Estimates of atmospheric deposition rates in 1997 show a consistent pattern of lower nitrogen input in the Western States and higher input in the Central and Eastern States (fig. 6). Atmospheric nitrogen is derived from two major sources: nitrogen oxides from combustion of fossil fuel and ammonia from volatilization of fertilizer and manure (U.S. Environmental Protection Agency, 2002b). The relatively high deposition in the Central and Eastern States is a result of the spatial distribution of these sources, the prevalence of westerly winds, and the general increase in precipitation eastward from the Great Plains.

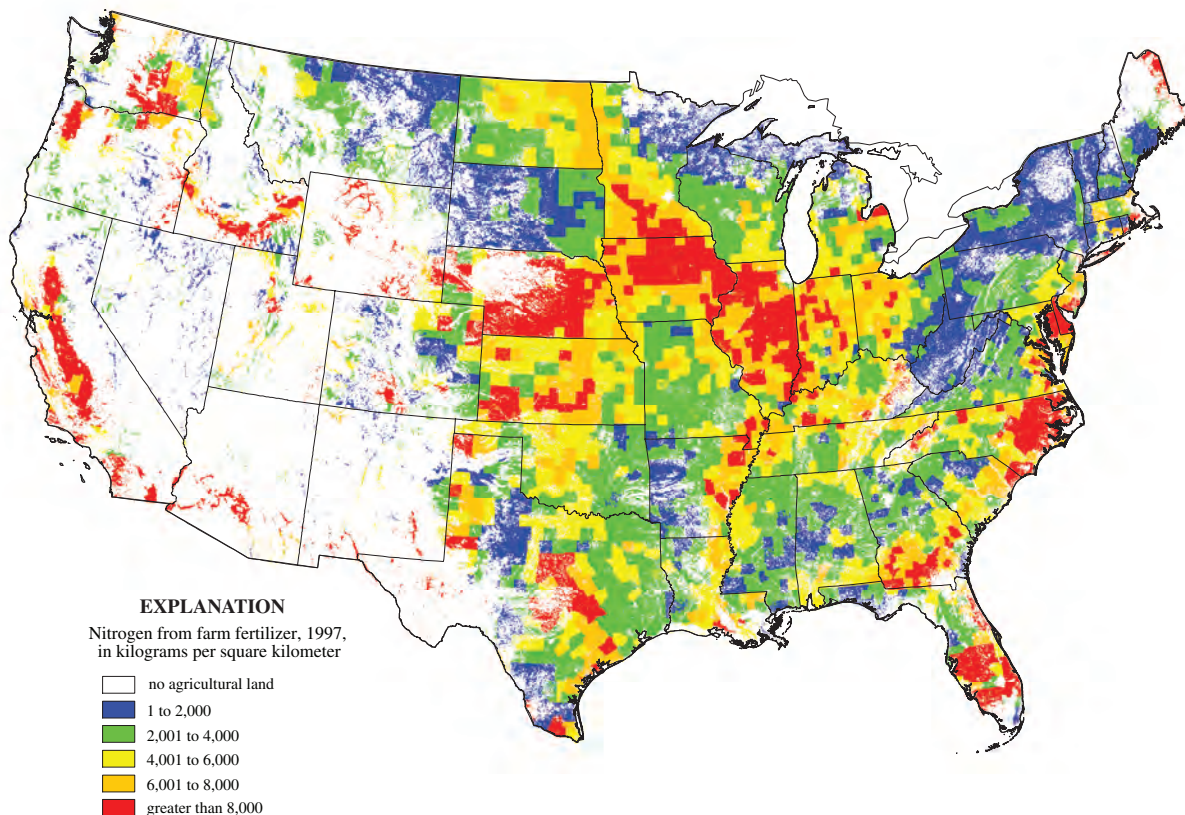


Figure 3. Nitrogen input from farm fertilizer, in 1997, allocated to agricultural land within a county.

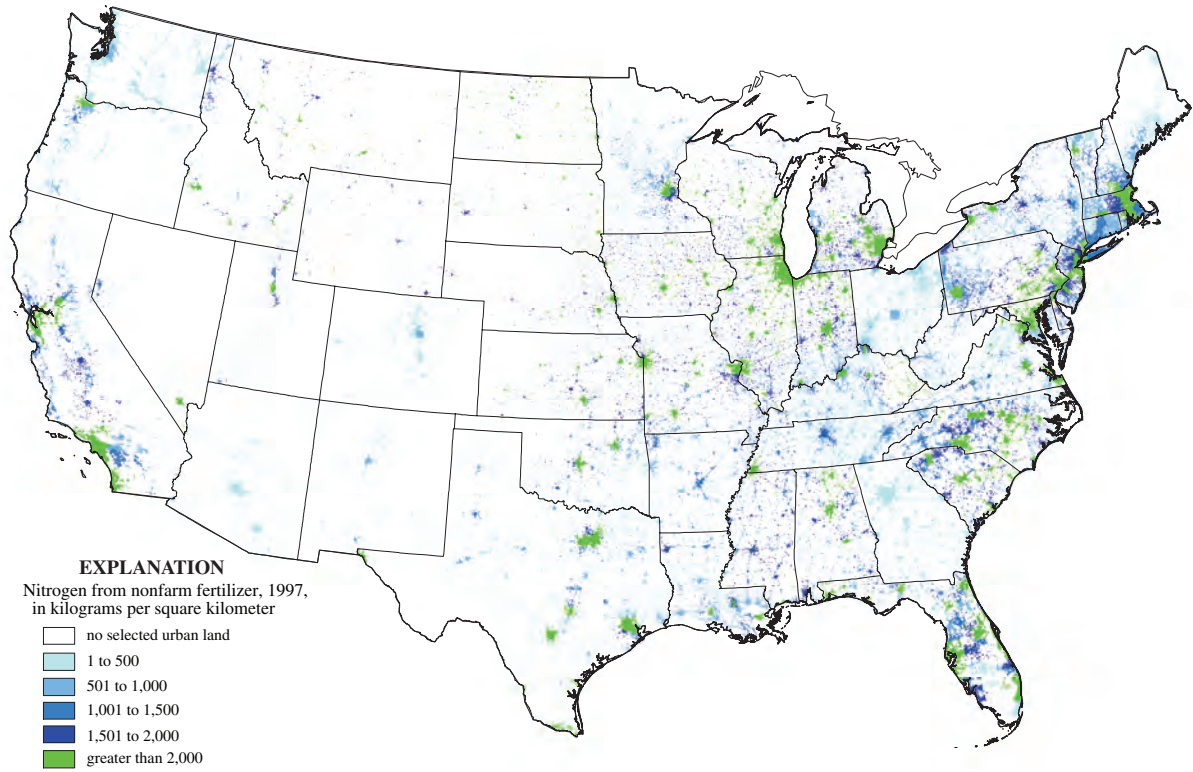


Figure 4. Nitrogen input from nonfarm fertilizer, in 1997, allocated to selected urban land within a county.

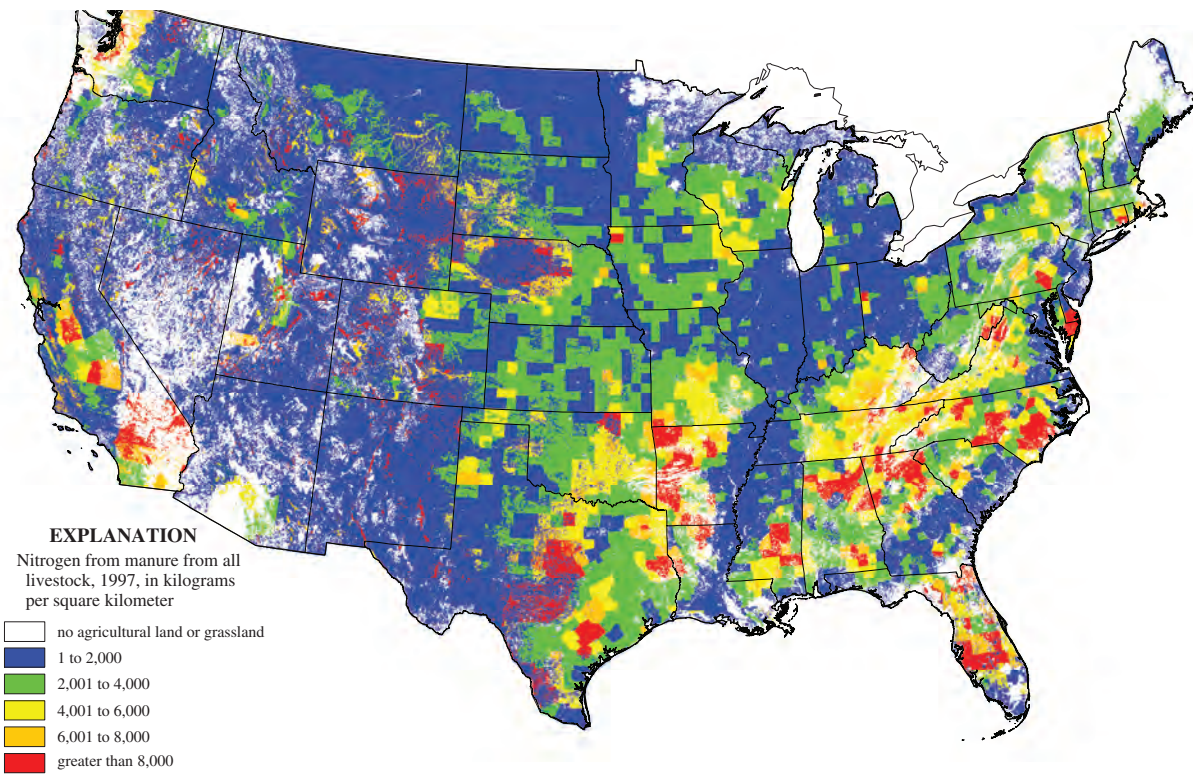


Figure 5. Nitrogen input from livestock manure, in 1997, allocated to agricultural and grassland within a county.

Temporal Changes in Nutrient Inputs

Annual estimates of nitrogen and phosphorus inputs from all sources estimated in this report are shown in figure 7. Also shown are previous estimates of nitrogen and phosphorus inputs from fertilizer for 1945 through 1986 (Alexander and Smith, 1990; Battaglin and Goolsby, 1995). Nitrogen input from fertilizer increased from less than 1 million metric tons per year before 1950 to more than 10 million metric tons per year by 1980. During the same time period (1950–1980) phosphorus inputs from fertilizer quadrupled to about 2 million metric tons per year. Since then, annual nutrient inputs from most sources have been approximately constant; however, nitrogen input from fertilizer has continued to increase but at a lower rate and with higher variability. Nitrogen input from atmospheric deposition increased slightly during 1985 through 1990 but since then has been approximately constant, within a narrow range of annual fluctuations (fig. 7). Because fertilizer is the largest single source of nitrogen, changes in fertilizer use have the greatest influence on total nitrogen inputs. Phosphorus inputs are affected about equally by fertilizer and manure sources.

National totals of nitrogen and phosphorus inputs from each source for 1987 and 1997 are listed in table 5. The relative proportions of each source, as a percentage of the total nitrogen or phosphorus input, were about the same in both

years. Inputs from all sources were greater in 1997; total nitrogen input increased by 14.0 percent and total phosphorus input increased by 10.6 percent. Both of these changes primarily were due to increases in farm-fertilizer use. Manure inputs increased slightly, but the percentage of total nitrogen and phosphorus contributed by manure decreased because of the relatively larger increases in nutrient inputs from farm fertilizer. The percent change for both nutrients from nonfarm-fertilizer use was large, but this source provides only a small fraction of the total input. Nitrogen input from atmospheric deposition in 1997 was 13.4 percent higher than in 1987 (table 5) but was about the same as annual atmospheric deposition from 1989 through 2001 (fig. 7).

The percent change in nitrogen input from farm-fertilizer use from 1987 to 1997 is shown in figure 8. The map shows a wide range of increases and decreases, generally within plus or minus 50 percent. Positive changes were somewhat more common, consistent with the overall increase of 18.5 percent nationally (table 5). Increases were small to moderate in many areas of intensive agriculture, such as Illinois, Iowa, the coastal Southeast, and the irrigated valleys in the West; but in other areas where fertilizer use is high, such as Ohio and Indiana, nitrogen input showed either little change or moderate decreases. The largest increases were in Montana, North Dakota, and Wyoming — areas of generally low application rates where a small increase in fertilizer use can result in a

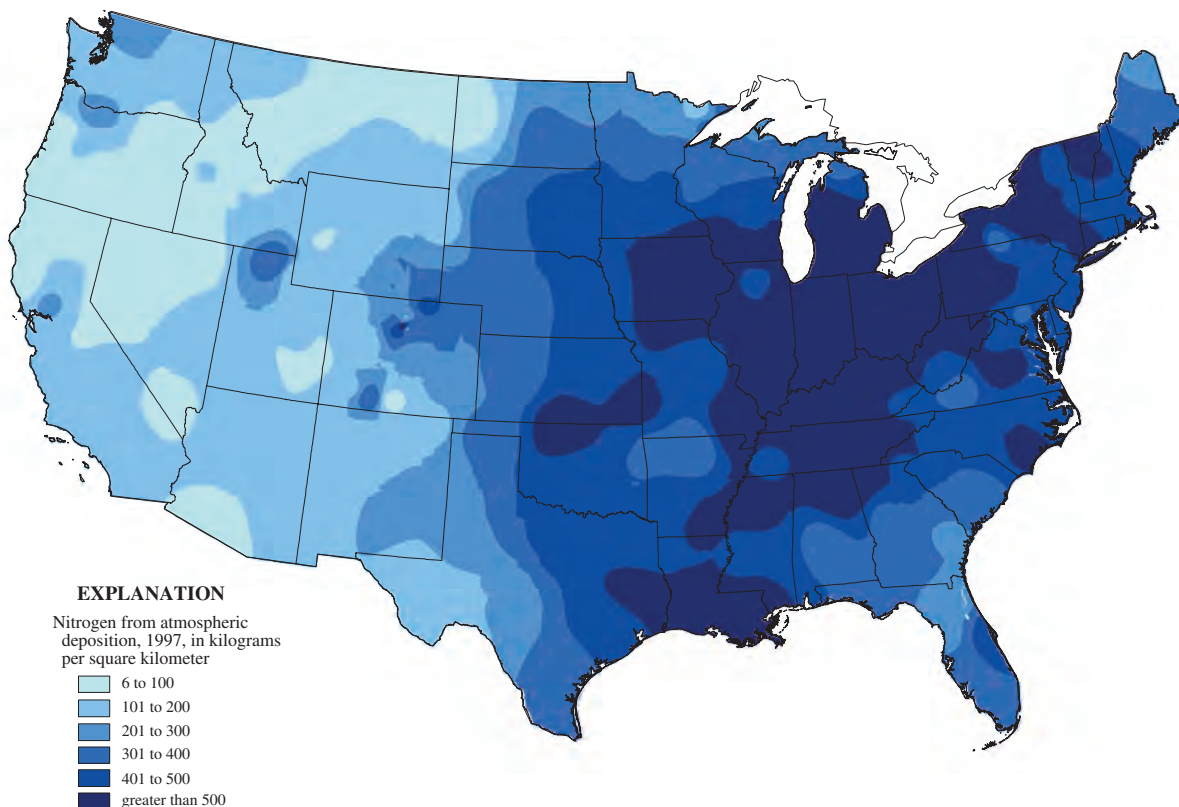


Figure 6. Nitrogen input from atmospheric deposition for 1997.

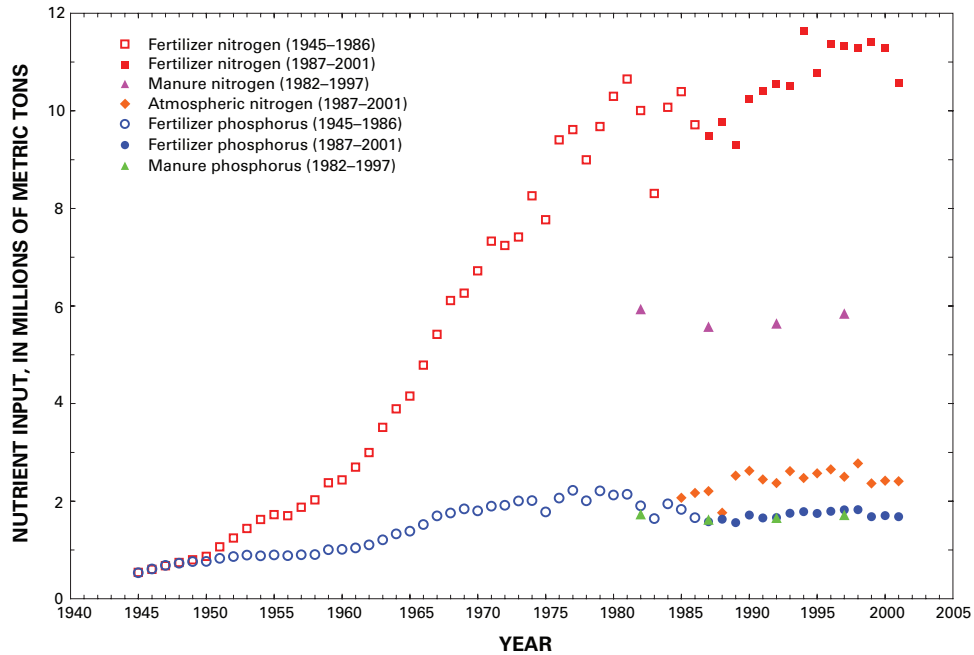


Figure 7. Annual nutrient inputs to the conterminous United States, 1945–2001.

Table 5. Nitrogen and phosphorus inputs in the conterminous United States for 1987 and 1997.

[--, not applicable]

Source	1987		1997		Percent change, 1987–1997
	Amount (millions of kilograms)	Percentage of total	Amount (millions of kilograms)	Percentage of total ¹	
Farm-fertilizer nitrogen	9,358	54.2	11,089	56.3	18.5
Nonfarm-fertilizer nitrogen	124	0.7	244	1.2	97.8
Manure nitrogen	5,575	32.3	5,844	29.7	4.8
Atmospheric nitrogen	2,206	12.8	2,502	12.7	13.4
Total nitrogen	17,262	--	19,679	--	14.0
Farm-fertilizer phosphorus	1,552	48.5	1,783	50.4	14.8
Nonfarm-fertilizer phosphorus	27	0.8	40	1.1	49.2
Manure phosphorus	1,622	50.7	1,717	48.5	5.8
Total phosphorus	3,201	--	3,539	--	10.6

¹ Total may not equal 100 due to rounding.

large percent change. Because these large changes generally occurred within State borders, they might be affected, in part, by differences in the way that States reported fertilizer sales for the 2 years.

The 1987 to 1997 change in nitrogen inputs from non-farm fertilizer is shown in figure 9. Inputs increased in most areas, reflecting the national increase of 97.8 percent listed in table 5. Decreases occurred in most or all areas within certain States, indicating that these changes might be due to changes in the way fertilizer sales were reported in these States. It should be noted that nationally, nonfarm-fertilizer use was more than an order of magnitude smaller than that of farm fertilizer use, so large percent changes in nonfarm nutrient inputs have little effect on total inputs.

Percent changes in nitrogen input from livestock manure are shown in figure 10. Small areas of large percent increases were offset by large areas of moderate percent decreases. Nationally, the change in nitrogen input from manure was

4.8 percent (table 5). The most extensive area of large increases was in North Carolina, where many confined animal feeding operations, particularly for hogs, were established during this time period (Gerry McMahon, U.S. Geological Survey, written commun., 2005). A large percent increase occurred in southern New Mexico. This increase may be deceptive because the actual nitrogen input from livestock manure in 1997 is small. Isolated areas of moderately large percent increases occurred in association with high nitrogen inputs, for example in central California and southern Idaho.

The change in atmospheric deposition between 1987 and 1997 was not evaluated. In general, input from atmospheric nitrogen deposition increased between 1987 and 1997 but was constant from 1989 through 2001. Spatial patterns of deposition are dependent upon weather conditions, such as annual precipitation and wind patterns; therefore changes in these patterns over time might not indicate increases or decreases in sources of atmospheric nitrogen.

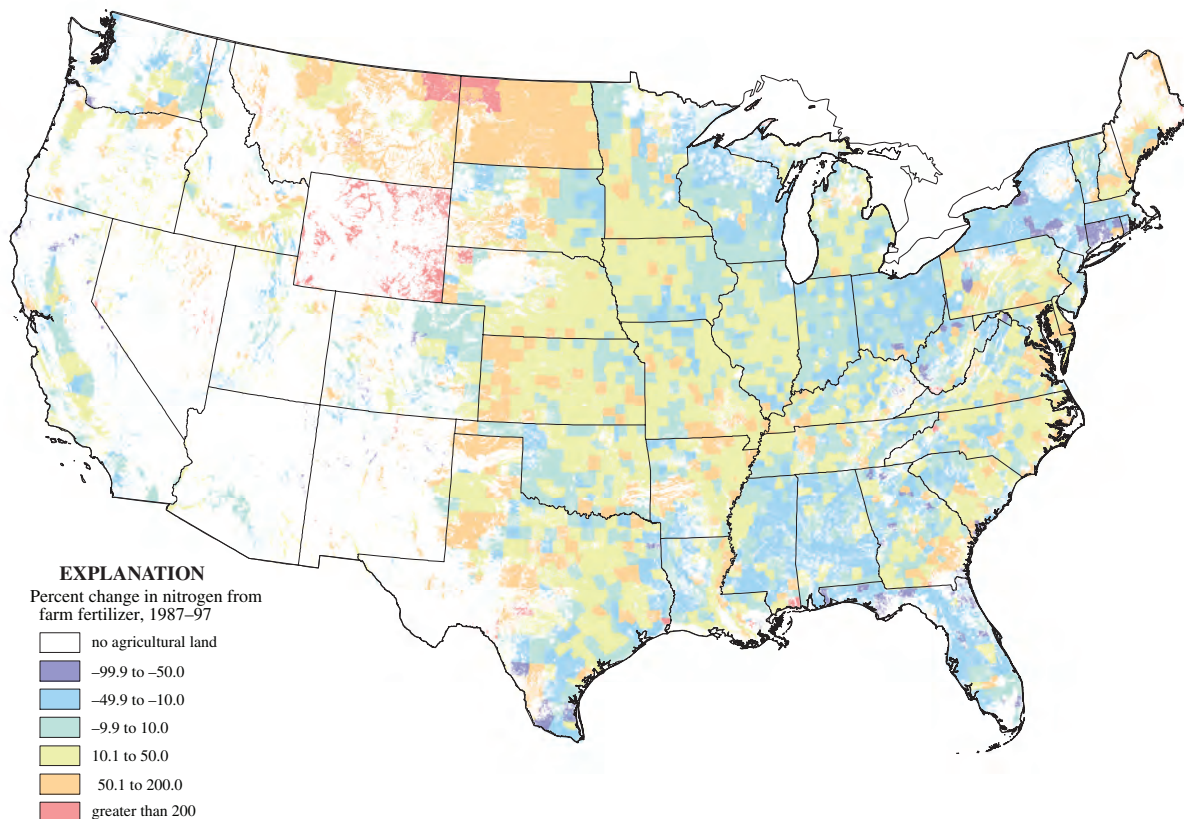


Figure 8. Percent change between 1987 and 1997 in nitrogen input from farm fertilizer allocated to agricultural land within a county.

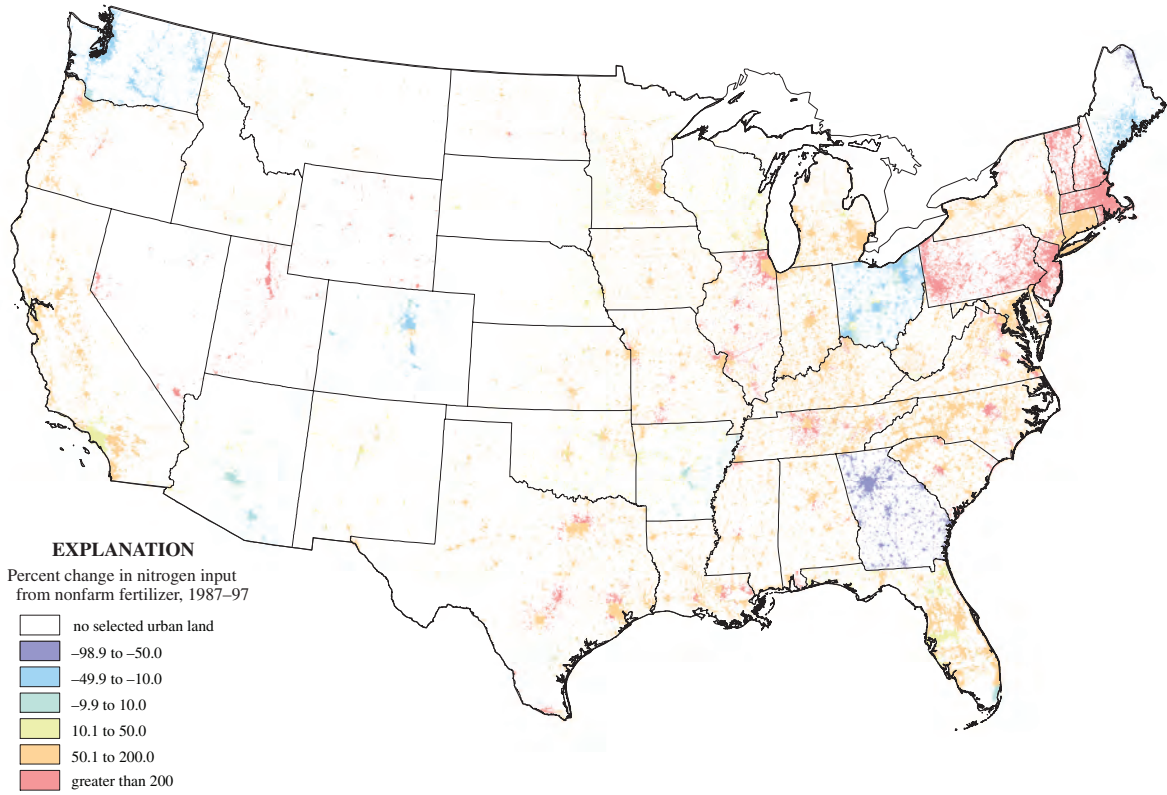


Figure 9. Percent change between 1987 and 1997 in nitrogen input from nonfarm fertilizer allocated to selected urban land within a county.

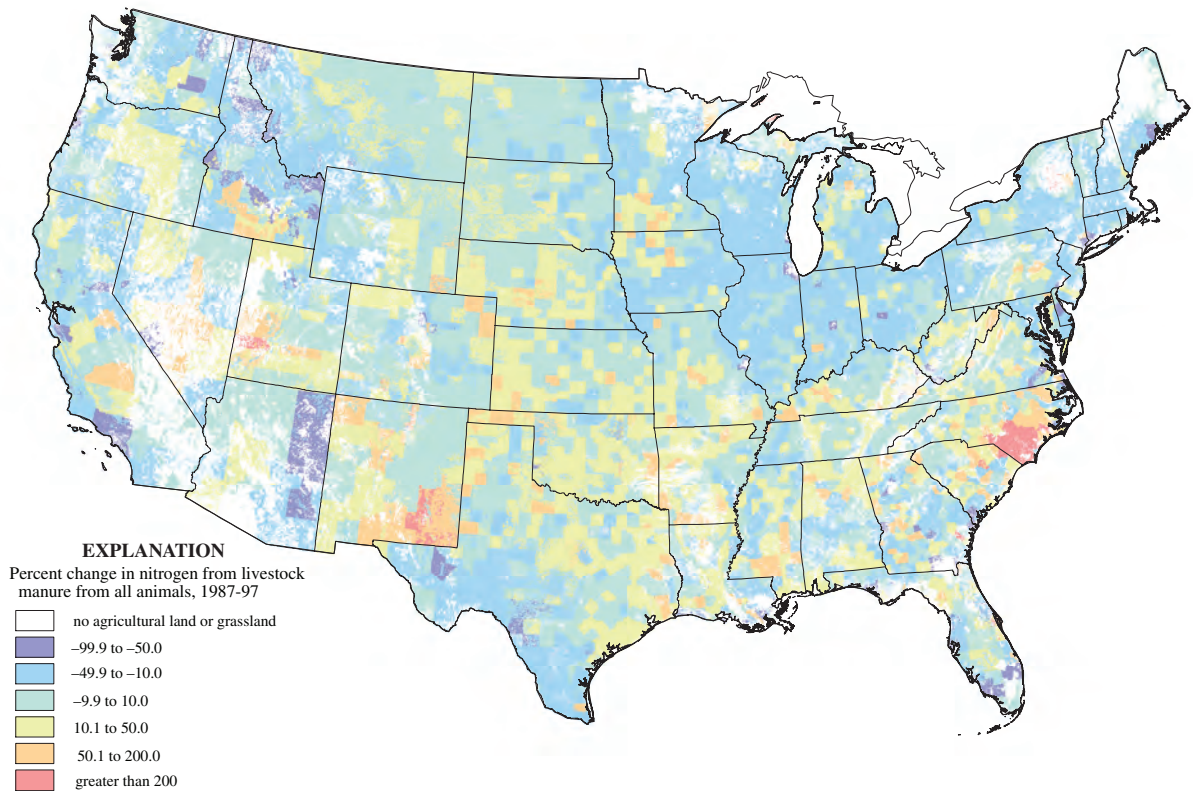


Figure 10. Percent change between 1987 and 1997 in nitrogen input from livestock manure allocated to agricultural land and grasslands within a county.

Summary

County-level nutrient input data for fertilizer use, livestock manure, and atmospheric deposition were estimated for the conterminous United States for the years 1982 through 2001. These data were estimated for use in the NAWQA Program for investigations of stream and ground-water quality including spatial and temporal variability. These data also could be used in other large-scale regional and national investigations. Nationally, the largest source of nitrogen was farm fertilizers, and the largest sources of phosphorus were farm fertilizers and livestock manure. Farm-fertilizer inputs were highest in areas of the upper Midwest, along the east coast, and in irrigated areas of the West. Nonfarm-fertilizer use was similar in major metropolitan areas throughout the Nation but was more extensive in the more populated Eastern and Central States and in California. Generally, inputs were highest toward the center of a metropolitan area and were lower in the outlying suburbs. Nitrogen from atmospheric deposition generally increased from west to east. This deposition pattern is related to the location of major sources (nitrogen oxides from fossil fuel combustion and ammonia from fertilizer and manure volatilization) and the effects of precipitation and prevailing winds.

The increases in total-nitrogen and total-phosphorus inputs between 1987 and 1997 were 14.0 and 10.6 percent respectively, and there were increases in nutrient inputs from all sources. Nitrogen input from nonfarm fertilizer almost doubled between 1987 and 1997, and phosphorus input from nonfarm fertilizer increased by one-third, but these inputs were small compared to other sources. The small change nationally in nutrient inputs from manure reflects the small changes in animal populations; however, increases and decreases in specific regions reflect changes in the livestock industry. Input from atmospheric nitrogen deposition also increased between 1987 and 1997 but was about constant from 1989 through 2001. All the changes in nutrient inputs during the period of this report are small compared to the increase in inputs from fertilizer use from 1945 through 1985.

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