USDA NRCS
Natural Resources Conservation Service

Water Quality and Agriculture
Status, Conditions, and Trends

Working
Paper #16

Water Quality and Agriculture:

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Contents:

Acknowledgments

This report, the result of extensive collaboration within the U.S. Department of Agriculture and with other departments, was prepared by John D. Sutton, USDA/NRCS. Key contributors include Joseph Bagdon, USDA/NRCS; Jerry Bernard, USDA/NRCS; Steve Brady, USDA/NRCS; Barry Burgan, U.S. EPA; Neil Carriker, TVA; George Cross, USDA/NRCS; Daniel Farrow, NOAA; Ronald Follett, USDA/ARS; Dennis Helsel, USGS; Anne Henderson, USDA/NRCS; Charles Job, U.S. EPA; Robert Kellogg, USDA/NRCS; Charles Lander, USDA/NRCS; Kenneth Lanfear, USGS; James Lewis, USDA/NRCS; James Maetzold, USDA/NRCS; Mark Ribaudo, USDA/ERS; Andrew Sharpley, USDA/ARS; E. Tim Smith, USGS; and Donald Woodward, USDA/NRCS. Clive Walker, USDA/NRCS provided an especially thorough and thoughtful review.

Resource analysis and assessments are ongoing functions of the Natural Resources Conservation Service. These assessments play an important role in how we keep the public and policymakers informed about emerging conservation and environmental issues, develop plans to conserve our natural resources, and design programs to provide national leadership for the conservation of natural resources on America's private lands. For additional information about this or other NRCS resource assessment publications, contact the Director of the Resource Assessment and Strategic Planning Division, USDA, Natural Resources Conservation Service, P.O. Box 2890, Washington, DC 20013.

July 1997

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Executive Summary

National opinion surveys reflect the public's concern that sediment from agricultural land, pesticides, and fertilizers from animal wastes and chemical applications may be contributing to surface and ground water pollution. This paper documents the national and regional status of and trends in water quality from the early 1980s to the early 1990s relative to these agricultural substances. It sets the stage for subsequent analysis of projected resource conditions under alternative social, economic, and environmental policies.

Chapter 1 concerns the important link between soil quality and water quality. The first part of Chapter 2 discusses sediment and erosion and their effect on water quality; the movement of nutrients and pesticides through the environment to water and how agricultural practices can reduce that movement; and regional salinization problems. The second part of Chapter 2 reflects the changes between 1982 and 1992 in soil erosion and the uses of nitrogen, phosphorus, and pesticides in agriculture. Chapter 3 discusses the complexities of measuring water quality.

Chapters 4 and 5 present national water quality status and trends. Chapter 4 synthesizes EPA's national compilation of separate State reports on the level, causes, and sources of impairment in the assessed portions of each State's surface water in 1992 and 1993. Chapter 5 relies heavily on U.S. Geological Survey (USGS) analyses to present monitored estimates of change in surface water quality over the past decade. It summarizes what little is known nationally about ground water quality. Finally, chapter 6 looks briefly at the environmental laws and programs affecting agriculture through the early 1990s when these changes in water quality were taking place.

Two fundamental factors impede a national water quality assessment. The first factor is the scarcity of nationally assembled, reliable data. The U.S. Environmental Protection Agency (EPA), for example, regularly summarizes the States' views on the quality of their surface water while simultaneously reporting on the serious difficulties encountered in aggregating these data into a national synthesis.

The second factor is the complexity of measuring water quality. The following measurement questions provide partial insight into this complexity:

- when to measure: periodically; during a storm's first 10 minutes or at a later point; during the planting season, or sometime after?
- where to measure: along the bank or mid-stream; just below the water's surface or on the streambed?
- how long to measure: for one, five, or more years?
- what to measure: which of the numerous physical, chemical, and biological indicators should be assessed? and
- the source of the pollutant: one or another farmer's field; sublateral flow from shallow ground water and urban runoff; or some other source?

Ground and surface water are interconnected. For example, ground water discharges account for some 40 percent of streamflow nationally; about 50 percent of the Chesapeake Bay's fresh water comes from ground water.

■ **Soil quality** is significant for water quality. Soils vary in ability to absorb, buffer, and transform chemical flows; retain and store floodwaters; support plant growth; and renew quality water supplies. Soil erosion has been the most widely used indicator of soil quality. Erosion on U.S. cropland declined significantly between 1982 and 1992 — from about 3.1 billion tons per year to about 2.1 billion tons per year. This dramatic change resulted in large part from the Conservation Reserve Program (CRP) and the conservation compliance provision of the 1985 Farm Bill. Under the CRP's 10-year contracts, the annual average erosion rate on 36.5 million enrolled acres has declined from 20.6 tons per acre to 1.6 tons per acre.

However, improving or protecting soil quality is broader than erosion control. Compaction, acidification, and loss of biological activity also affect soils in several ways: they reduce the soils' nutrient and water storage capacities, increase the mobility of chemicals, slow the rate of animal waste or chemical degradation, and reduce the efficiencies of plant root systems. These factors can increase the likelihood that excess nutrients, pesticides, salts, and sedimentation will occur in water.

■ **Sediment** is the product of soil erosion. Eroded soil is deposited in waterbodies. Based on river and stream miles assessed by the States in 1992 and 1993, EPA reports that silt (a size class of sediment particles) and other suspended solids (primarily clay particles) from agricultural and nonagricultural sources are the leading cause of impairment for rivers and streams and the second leading cause for lakes, reservoirs, and estuaries. An estimated 60 percent of total riverborne sediment comes from irrigated and nonirrigated agricultural fields. Because eroding soil can be temporarily stored in low spots on the landscape, the time necessary to document a reduction in sediment after a reduction in soil erosion varies greatly — from days to centuries.

Sediments transport nutrients, pesticides, pathogens, and toxic substances into surface water. High sediment loads reduce the aesthetic appeal of water bodies, inhibit the health of stream biota, reduce plant photosynthesis, and suffocate spawning and feeding populations. Sediment deposited on floodplains can affect crop yields.

From 1980 to 1989, suspended sediment in rivers and streams showed highest average concentrations in the west-central regions and lowest in the Atlantic States, Great Lakes, and Pacific Northwest. A national trend is difficult to discern as different studies suggest different results. One study indicates a very slight but irregular decline in sediment accumulations in 85 large reservoirs from 1980 to 1989. Another study concludes that annual sediment deposition rates increased almost fivefold from 1970 to 1985 compared to the period between 1950 and 1970.

■ **Nutrients**, including nitrates and phosphorus from agricultural and nonagricultural sources, are the leading cause of impairment in lakes and reservoirs and in estuaries and the third most reported cause in rivers and streams, according to surface water assessments performed by the States in 1992 and 1993.

■ **Nitrogen** continually cycles among plants, soils, water, and the atmosphere. It is added to soils from commercial fertilizers, animal manure, and legumes such as soybeans. Achieving balance between crop needs and amounts supplied during the growing season requires sophisticated land management. The principal form of nitrogen found in ground and surface water is nitrate. Nitrate in excess of plant needs travels in runoff, leaches through soil, or volatizes to the atmosphere. A high concentration of nitrate in drinking water poses a potential threat to human health, particularly among infants. High nitrate concentrations in surface water, especially estuaries, contribute to eutrophication and the excessive growth of aquatic plants, which leads to unpleasant odors and insufficient dissolved oxygen for fish and other organisms.

From 1982 to 1992, total commercial nitrogen consumption for all farm and nonfarm applications (the data are not separately available) rose only 4.7 percent. The region with the largest consumption, the Corn Belt, registered a 3.5 percent decrease. Nationally, the fertilized acreage of cropland and grazing land was nearly unchanged.

Agricultural practices can reduce the amount of nitrogen lost to the environment. For example, farmers may

- tailor nitrogen application rates to plant needs during the season instead of making one large application at planting;
- apply nitrogen in a quantity designed to achieve realistic crop yields and reasonable economic returns;
- use conservation tillage to reduce erosion and runoff to surface water while considering the effect of tillage on nitrogen leaching;
- grow crops in rotations that biologically fix nitrogen or that use less nitrogen than monocultures of corn and wheat,
- use winter cover crops that consume nitrate and available soil moisture; and
- use vegetative filter strips to trap sediment and particulate nitrogen.

■ **Livestock manure** is a major source of nitrogen and phosphorus. Not including nutrient losses to the environment that occur during manure collection and handling or the manure excreted by grazing animals, manures applied to cropland in 1992 contained an estimated 1.7 million tons of organic nitrogen and 1.2 million tons of phosphorus. Cattle and calves and dairy animals together produced four-fifths of these nutrients. Broilers produced significant shares of the organic nitrogen and phosphorus.

The practice of confining livestock in large feedlots often results in more manure than there is cropland for its disposal. In instances where feed is transported to these large facilities and if the watershed in which they are located has insufficient cropland to fully process these nutrients, the excess application results in leaching and runoff of nutrients.

From 1980 to 1989, river and stream water quality monitoring data show that nitrate concentrations tended to decrease as often as they increased. This finding is a noteworthy change from 1974 to 1981, when increases were widespread nationally. Regionally, the eastern, south-central, and southeastern United States showed predominantly downward trends. In each of the 14 major water resource regions that comprise the conterminous United States, the annual percentages in monitored nitrate per square mile either decreased or changed very little.

USGS analysis of ground water samples from 23 large areas across the United States indicates a median nitrate concentration of 0.6 milligrams per liter (mg/L), a level much below EPA's 10 mg/L standard for nitrate in drinking water. Median concentrations were lowest in public water supply wells (0.2 mg/L) and highest in irrigation and livestock wells (2.4 mg/L). Only 1 percent of the median concentrations in public water supply wells exceed the EPA standard.

■ **Phosphorus** is essential for plant growth. Over 75 percent of its loss from cropland is in runoff to surface water. Excessive concentrations of phosphorus in surface water accelerate eutrophication. Because phosphorus is not as soluble as nitrogen, it is less a problem to ground water.

Nationally, fertilizers account for four-fifths of the phosphorus added to cropland. However, phosphorus from animal manures can be significant, especially in regions with large confined-animal operations. Manure applications based on a crop's nitrogen needs have led to phosphorus accumulation in many soils because manures contain relatively high concentrations of phosphorus compared to that needed by plants. Rural, noncultivated lands can be a source of "background loading" significant enough to cause eutrophication, and this source cannot be effectively reduced.

From 1982 to 1992, farm and nonfarm commercial phosphorus consumption dropped 22 percent nationally. The Corn Belt, the largest regional user, experienced a 21 percent drop. Nationally, river and stream monitoring data for 1982 to 1989 showed widespread declines in total phosphorus concentrations. Of the 14 national water resource regions, 13 recorded monitored reductions in tons of phosphorus per square mile.

Options to manage phosphorus sources more effectively include basing fertilizer application and placement on eutrophic and agronomic considerations. Where soil phosphorus tests are high, applications may even be eliminated. Practices to minimize runoff include subsurface application, conservation tillage, buffer and filter strips, crop rotations with legumes, terracing, contouring, and use of cover crops.

■ **Fecal contamination** sources include runoff from confined animal facilities, pastures, and urban areas; untreated sewage; and effluent from sewage treatment plants. Most concentrations of fecal coliform bacteria indicate fecal contamination from warmblooded animals. During the 1980s, national river and stream monitoring data suggest widespread concentrations above the acceptable limit. However, all trends suggest that control of point and nonpoint sources improved over the decade. Regionally, concentrations were highest in midwestern and southcentral States.

■ **Salinity** is associated with inadequate drainage wherever it occurs. It is frequent in arid and semiarid areas because precipitation can be insufficient to induce adequate percolation and because pothole areas and closed basins are common. About 14 million irrigated acres are affected by salt. Two examples illustrate the problem for irrigated areas.

In California's San Joaquin Valley, shallow ground water, inadequate drainage and irrigation-induced leaching, evapotranspiration, and naturally occurring salts in arid soils result in a significant salinity and selenium problem. Producers are implementing improvements in irrigation practices, irrigation scheduling, and water table management and reusing irrigation drainage water on salt-tolerant crops to address the salinity buildup on their farms.

In the Colorado River basin, salt contamination comes from evaporated irrigation water and the leaching of excessive irrigation water through ancient salt deposits. Salinity in the lower Colorado has been reduced by completion of the filling of Lake Powell, repurchase and retirement of irrigated lands by the Bureau of Reclamation, and producer adoption of practices to improve canal linings, reduce deep percolation, and improve irrigation scheduling.

■ **Pesticides** are heavily used in agriculture. About 75 percent of all pesticide expenditures in the United States are agricultural, and 70 percent of these are for herbicides, particularly for use on corn. Use has trended slightly downward since the early 1980s. Monitoring indicates that (a) definite problem areas usually involve chemicals that are already banned or restricted; (b) pesticides occur relatively infrequently in ground water, typically at low levels, and then usually in the older, shallow wells; and (c) the most persistent agricultural pesticides are frequently found in surface water during field application, but are not otherwise detected or only at low levels. Since monitoring studies have largely concentrated on the Midwest and other areas of heavy use, the extent to which pesticide residues are a national problem is not known. Further, little is known about the human health and environmental effects of the generally low levels that have been found. Farmers and ranchers are modifying their management practices to reduce their reliance on agricultural pesticides. Systems of integrated pest management, for example, are on the upswing.

■ **In sum**, from the early 1980s to the early 1990s, changes in agricultural land use, management, and water quality monitoring suggest a national trend toward less contamination of surface water by agrichemicals and perhaps sediment. The degree of progress, of course, varies locally and regionally. USGS reports a general tendency toward constant or declining nitrate concentrations in streams, in contrast to the widespread increases reported from 1974 to 1981; and widespread declines in fecal coliform bacteria and total phosphorus in streams, large reservoirs, and coastal waters. Although off-field soil erosion declined significantly during the decade, this reduction cannot be directly translated into a discernible trend for suspended sediment. Agricultural pesticide use has declined slightly and management has become more sophisticated, though persistent pesticides are still found in surface water during periods of field application. Ground water monitoring indicates very low nitrate concentrations and infrequent low-level pesticide occurrences in ground water. Management changes by farmers and ranchers to reduce the probability of nutrient and pesticide losses to the environment augur well for the future.

Introduction

Since the passage of the Clean Water Act (CWA; but also known as the Federal Water Pollution Control Act Amendments of 1972 [Pub. L. 92-500]), the private and public sectors have spent an estimated $541 billion on water pollution control. Nearly all of this money has been spent on “end-of-the-pipe” or “point” sources of pollution that are mainly municipal and industrial (Knopman and Smith, 1993). The Nation has made progress in controlling and reducing certain kinds of chemical pollution in its waters, primarily from point sources such as municipal treatment plants and industrial discharges, and from reduced use of certain agricultural pesticides such as DDT and other chlorinated hydrocarbons. As a result, chemical water quality in many rivers and lakes has improved (National Research Council 1992).

The public continues to be concerned about water pollution and water quality. A 1993 national survey of adult opinion found that 67 percent of those interviewed think that the pollution of America’s rivers, lakes, and streams is “extremely” or “very dangerous” for the environment. Only 7 percent said that such pollution is not dangerous (National Opinion Research Center, 1993). Many public and private groups emphasize that a great deal of work remains (*Water Quality 2000*, 1992).

Most informed observers agree that national water quality programs have not been effective in reducing “nonpoint” or diffuse sources. Nonpoint sources include runoff and leaching from city streets, farm fields, mining and construction sites; saltwater intrusion; precipitation; and atmospheric deposition.

Agriculture is very much at the center of nonpoint source concern. When asked in a 1993 national survey about the environmental danger inherent in pesticides and chemicals used in farming, 38 percent of respondents said that pesticides are “extremely or very dangerous,” and 48 percent said they are “somewhat dangerous” (National Opinion Research Center, 1993).

A 1993 National Research Council report states that nutrients (nitrogen and phosphorus) and sediments, substances closely associated with agricultural production, affect surface water quality in the United States and that loadings of these substances to water have increased in agricultural watersheds. Pesticides have also been reported in surface waters, especially in the spring following pesticide application to crops. The same study reports that agricultural chemicals have been detected below ground in both shallow and deep aquifers (National Research Council, 1993). These concerns were echoed in the Second RCA Appraisal: “Agricultural land is the greatest contributor to [the] nonpoint source pollution” of ground and surface water (U.S. Department of Agriculture, 1989).

Sediment, nutrients, pesticides, and soluble salts become pollutants when they are lost from the farm or ranch operation through leaching, runoff, and airborne volatilization or drift. In fact, when chemicals of any kind are used in excess of plant needs, they can migrate beyond the field and become an environmental burden.

■ **Sediment** has been called a soil resource out of place. Sediment is eroded soil deposited on the land and in streams, rivers, drainage ways, and lakes. It degrades water quality and often contains agrichemicals. It clogs irrigation canals, reservoirs, estuaries, and harbors — reducing the efficiency of these structures and often requiring expensive repair (National Research Council 1993).

■ **Nitrogen**, an essential plant nutrient, continually cycles between plants, soil, water, and the atmosphere. Throughout this cycle, nitrogen undergoes complex biochemical transformation to nitrate, a water soluble form that is easily absorbed by plant roots. Excess nitrate can run off and leach through the soil, potentially polluting both ground and surface water. The EPA has established a water quality standard of 10 mg/L of nitrate for drinking water. This level is rarely exceeded in public water supplies. Nitrogen compounds sometimes cause eutrophication — especially of estuaries. The eutrophication process depletes oxygen, kills fish, and results in cloudy, putrid water.

■ **Phosphorus**, another essential nutrient, is the agent responsible for eutrophication in water bodies in which it is the limiting nutrient. Excessive phosphorus will support unlimited rates of aquatic plant growth that choke the waterbody.

■ **Pesticides** cost the agricultural sector about $6 billion annually. For many, pesticides are key to producing a nationally abundant supply of low-cost food and fiber. Some 70 percent of the pesticides used in agriculture are herbicides. Monitoring studies show that pesticides occur in surface water and ground water, sometimes at levels that exceed health standards.

■ **Salinity** affects germination, seedling and vegetation growth, and reduces crop yields. A high level of sodium intake, especially if not balanced by calcium, is a common contributor to human health problems. Soil salinity, stemming primarily from irrigation but also from saline seeps and coastal saltwater intrusion, can accumulate in root zones to the point that plants are unable to assimilate water (National Research Council 1993).

In assessing water quality status and trends, three key issues must be kept in mind:

- The definition or degree of water "quality" differs among individuals.
- Water quantity and water quality are directly linked.
- There is a general lack of nationally consistent, reliable water quality data.

Water quality is defined for each water resource based on its designated uses. For example, although the water body may be fine if it is to be used for irrigation or aesthetic enjoyment from a distance, it may be deemed slightly impaired if its designated use includes general fishing, or severely impaired if it is to be used as a coldwater salmon habitat or as drinking water. Opinions often differ about the principal uses of a particular water body. For example, in categorizing the use of a river shared by two States, one State may have flood management as a priority; the other State may want to maintain the river's free-flowing, wild character.

Actions that reduce water *quantity* may have positive or negative effects on water *quality*. In a July 1994 ruling, the U.S. Supreme Court said that States can require minimum flows under the Clean Water Act. Justice O'Connor, writing for the majority, wrote that "in many cases, water quantity is closely related to water quality: a sufficient lowering of the water quantity in a body of water could destroy all of its designated uses, be it for drinking water, recreation, navigation or, as here, as a fishery" (Supreme Court broadens States' control, 1994).

Relationships between water quality and quantity are complex. For example, excessive livestock grazing affects a watershed by removing protective plant cover and compacting soils. Reducing the vegetation can increase the impact of raindrops, decrease the soil organic matter and aggregates, increase surface crusts, decrease infiltration rates, and increase erosion. These conditions then lead to increased runoff and reduced soil water content, which can decrease water quantity; and to increased transport of topsoil and nutrients, which can decrease water quality. Fortunately, proper land treatment and conservation measures can improve water quality and augment and perpetuate the water supply in streams and ground water systems (Hendricks, 1994).

Turning to the data problem, scientific and nationally consistent data on both surface water and ground water quality are greatly lacking. The *National Water Summary 1990-91* (U.S. Geo. Surv. 1993) contains the major share of available nationally consistent, measured water quality data for rivers and streams. A similar database, however, does not exist for lakes, reservoirs, estuaries, or ground water. The absence of information on ground water quality and quantity is especially troublesome as some 40 percent of streamflow nationally comes from ground water (Browner, 1994). This data problem encompasses the degree of a waterbody's impairment, the causes of its impairment, and the impairment's effects on the water's use.

This document on water quality and agriculture addresses the lack of data, the nature of potential agricultural pollutants, and changes in the use or production of agricultural substances and water quality in the 1982 to 1992 period. Chapter 1 presents an overview of water quality, soil quality, and potential pollutants from agriculture. Chapter 2 presents a more detailed discussion of the latter — how they are used, how they move through the environment to water, and how agricultural producers can protect water resources from their effects. Chapter 3 discusses the complexities of monitoring water quality with attention to agricultural substances. Chapter 4 provides a snapshot of the impairments and the sources and causes of impairments in a portion of the Nation's surface water. Chapter 5 presents the status, conditions, and trends in water quality directly attributable to substances associated with agricultural production. In the absence of a comprehensive national database, a variety of sources independently developed by USDA and other governmental agencies — especially EPA and USGS — are synthesized to present as complete a picture as possible. Chapter 6 briefly reviews major federal policies and programs in effect since the early 1980s that directly concern agricultural nonpoint source water pollution.

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Chapter 1 Soil Quality and Water Quality

Maintenance of soil quality through proper land management is key to determining whether agriculture or other land uses will cause or prevent water pollution. Society in general views soils simply as a medium in which to root plants, often failing to recognize that soils regulate and partition waterflow and buffer against human use and environmental changes.

Importance of soil quality

Society derives environmental and resource benefits from soil — it supports plant growth; absorbs, buffers, and transforms chemical flows; retains and stores flood water; and renews water supplies. Soil also supports buildings, roads and other human constructions. Soil quality is the capacity of the soil to perform these beneficial functions (Berc and Mausbach, 1994). As soils naturally vary in their capacity to perform these functions, a soil of excellent quality for one function may be unsuitable for another. Soil quality is, then, relative to a particular function or land use.

The quality of a soil is determined by a combination of properties — texture, water-holding capacity, porosity, organic matter content, and depth, among others. Historically, soil quality has been closely related to soil productivity (Natl. Res. Counc. 1993). However, the functions soils perform in natural and agricultural ecosystems go well beyond promoting the growth of plants. While we know a great deal about the relationships of specific soil attributes to soil quality, more research is needed to (a) identify key indicators of soil quality and (b) to establish reliable, generally accepted methods of measuring changes in soil quality.

Soil quality indicators

For at least 50 years, soil erosion has been a widely used soil quality indicator. For example, the NRCS National Resources Inventory (NRI), the most extensive and quantitative inventory of U.S. soil resources, has focused on measuring erosion. Soil erosion refers to the dislodgment of a soil particle by water or wind from its resting place on earth. The key types of erosion are sheet and rill, ephemeral gully, classic gully, streambank, and wind. In its 1982, 1987, and 1992 inventory cycles, NRI focused on measures of sheet and rill erosion and wind erosion.

The soil loss tolerance (T) continues as the acceptable standard to evaluate soil erosion. For cropland and pastureland, acceptable levels of erosion range between 1 and 5 tons per acre per year, depending on the soil. In recent years, however, the usefulness of T as a measure of soil quality both before and after erosion has been increasingly questioned (Woodward, 1994).

Key factors in reducing erosion during the 1982 to 1992 period were the Conservation Reserve Program (CRP), adherence to the conservation compliance provisions of the 1985 and 1990 Farm Bills, increases in conservation tillage, and increased levels of crop residue left on the soil surface.

In 1982, sheet and rill erosion on private nonfederal lands was 1.7 billion tons; wind erosion was 1.4 billion tons. By 1992, these levels had fallen significantly — to 1.2 billion tons and 0.9 billion tons, respectively. Cropland acres eroding at rates greater than T contracted nearly one-third, from 180 million acres in 1982 to 125 million acres in 1992 (Woodward, 1994). More details on soil conservation programs and progress are presented in Chapter 2.

Improving or protecting soil quality is, however, a broader undertaking than erosion control. Preserving soil quality requires protecting the physical, chemical, and biological functions of soils as well as the position of soils on the landscape. For example, biological activity not only contributes to nutrient and water availability for plant growth, it also contributes to water quality.

Soil quality degradation leads directly and indirectly to water quality degradation (fig. 1-1). Soil degradation from erosion degrades water quality directly through the delivery of sediments and attached agricultural chemicals to surface water.

But soil degradation also has indirect effects on surface and ground water quality that are equally significant. Lost soil depth, increased compaction, acidification, and reduced biological activity contribute indirectly to water quality. Soil erosion and compaction hinder the watershed's ability to capture and store precipitation; they also alter its streamflow regimes by exaggerating seasonal flow patterns. These conditions increase the frequency, severity, and unpredictability of high-level flows and extend the duration of low-flow periods. The increased energy of runoff water further erodes stream channels, thereby adding to sediment loads and degrading aquatic habitat for fish and other wildlife.

The multiple effects of erosion, compaction, acidification, and loss of biological activity compound water quality problems. They reduce the nutrient and water storage capacities of soils, increase the mobility of agricultural chemicals, slow the rate of waste or chemical degradation, and reduce the efficiency of root systems. These factors in turn increase the likelihood that nutrients, pesticides, and salts will be lost from farming systems to both surface and ground water.

Not all soil degradation is equally damaging. Erosion, salinization, and compaction by wheeled traffic, for example, cause significant effects that are not easily reversible. Acidification, on the other hand, though important, is almost always reversible through proper management.

Biological degradation — closely related to organic matter content — is difficult to define. Soil biological activity significantly affects all other soil quality attributes and the capacity of soil to function as an environmental buffer and water regulator.

Degradation processes interact to accelerate soil degradation. Soil compaction, for example, reduces the soil's water-holding capacity, which in turn, increases surface runoff and accelerates erosion. And erosion, as we know, further reduces the soil biological activity by stripping away organically enriched topsoil.

Management can improve or degrade soil quality. For example, soil quality can be improved by leaving crop residues and plants; by adding organic matter through crop rotations, manures, or crop residues; and by carefully managing fertilizers, pesticides, tillage equipment, and other farming elements. Erosion control is clearly an important way to conserve and enhance soil quality, but it is not the only means. For greater detail on these practices and others, see Chapter 2.

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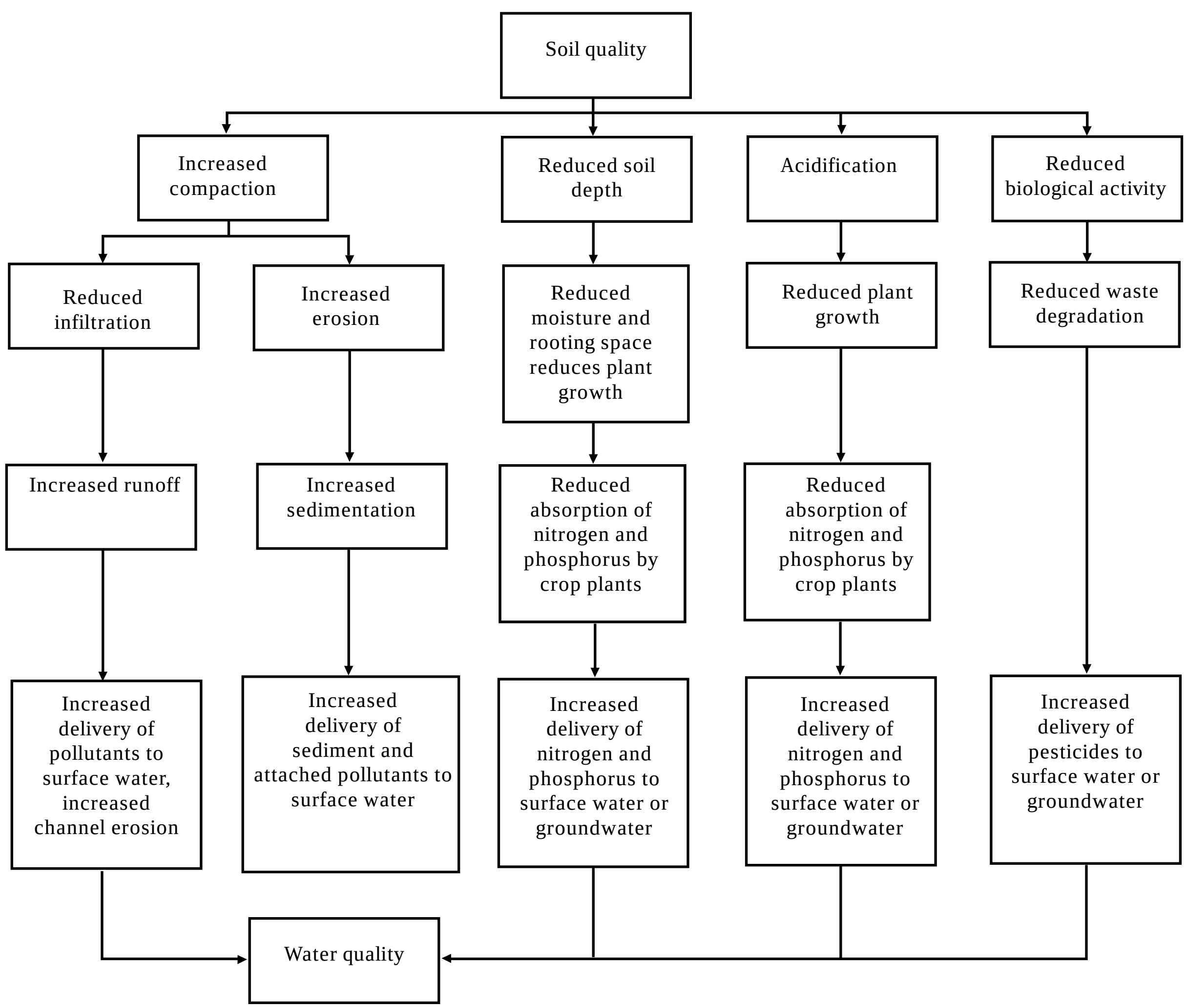
Figure 1-1 Changes in soil quality affect water quality (Natl. Res. Council, 1993)



Chapter 2 Agrichemical Links to Water Quality

This chapter examines the nature of potential pollutants, namely, sediment, fertilizers, pesticides, and salts; their movement within the landscape; and environmental effects. It also discusses trends and changes in agricultural practices that affect their movement to surface and ground water.

Sediment

In its *National Water Quality Inventory: 1992 Report to Congress*, EPA concluded that "siltation and nutrients impair more miles of assessed rivers and streams than any other pollutants, affecting 45 percent and 37 percent of impaired rivers and streams, respectively (U.S. Environmental Protection Agency, 1994). In addition, siltation is the second largest pollutant, after nutrients, affecting the intended uses of lakes, and the main nonpoint source pollutant affecting wetlands, with metals and nutrients second and third.[1]

Controlling sediment is an important first step in managing water quality problems. As rich, productive topsoil erodes through the physical and chemical forces of weathering, it becomes sediment suspended in water and deposited where it is not wanted. Not only is sediment aesthetically unpleasant, it also carries chemical contaminants, fills up water bodies, and causes physical damage to farmland, wildlife, water treatment systems, and power generators.

High concentrations of suspended sediment in streams diminish their recreational uses because pathogens and toxic substances commonly associated with suspended sediment are threats to public health. High sediment concentrations reduce water clarity and the aesthetic appeal of streams. Suspended sediment is also harmful to stream biota; it inhibits respiration and feeding, diminishes the transmission of light needed for plant photosynthesis, and promotes infections (U.S. EPA, 1986). Sediment deposited on the streambed can suffocate benthic organisms, especially in the embryonic and larval stages. Most sediment must be removed from water intended for human use, and high sediment concentrations add significantly to the cost of water treatment. Suspended sediment can also cause significant wear to bridge footings and other stream structures. Sediment accumulations in reservoirs decrease their storage capacity and threaten their safe operation by forcing spillways to flow more often or longer.

[1] The term "siltation" is often inappropriately used to mean sediment in general. Silt is a range of particle sizes ranging from 0.002 mm to 0.05 mm in diameter. The other principal class of "suspended solids" are clay particles ranging up to 0.002 mm in diameter. Sands, gravels, and rocks are not usually measured as suspended sediments.

Erosion control alone is not sufficient to solve all sediment pollution problems. Conservation farming practices can significantly reduce sediment transport, but even small particles will carry some chemicals. In addition, some sediment sources, such as classic gullies and streambank erosion, are not easily controlled and are often beyond an individual land user's ability to control or fix. In some western areas, for example, the Badlands of South Dakota, high rates of geologic erosion continue to occur on lands not cultivated or disturbed by human activities.

Sediment is the product of soil erosion—eroded soil is deposited in streams, rivers, and lakes. Understanding the linkage between sediment damages and erosion is fundamental to making any plans to protect ecosystems. The National Research Council (1993) summarizes the magnitude of the relationship between erosion of agricultural lands and the sediment produced:

> *Agriculture has a great impact on sediments deposition. Judson (1981) estimated that worldwide river-borne sediments carried into the oceans increased from 9 billion metric tons (10 billion tons) per year before the introduction of intensive agriculture, grazing, and other activities to between 23 billion and 45 billion metric tons (25 billion and 50 billion tons) thereafter. . . . Of the total 0.9 billion metric tons (1 billion tons) carried by rivers from the continental United States, about 60 percent is estimated to be from agricultural lands (National Resource Council, 1974). Several million cubic meters of sediment are washed into U.S. rivers, harbors, and reservoirs each year.*

Different erosion processes produce different sediment qualities. Sheet or interill erosion normally produces fine-textured sediment from the topmost soil layers. These layers contain the bulk of agriculturally applied chemicals that attach to and move with the sediment. Channel erosion produces sediment from all soil layers incised by this erosion process. Channel erosion in the uplands includes classic and ephemeral gullies that may be temporarily masked by normal tillage operations. Streambanks erode into previously deposited alluvial sediments that normally do not contain significant amounts of agrichemicals. Sediment deposited in and along streams may, however, sequester agriculturally applied chemicals. Relict pesticides such as DDT continue to show up in sampling because they are stored in beds or streambanks.

Knowledge of the texture or grain size of damaging sediment is key to its control. For example, sediment can be generalized as coarse (boulders, cobbles, gravel, sand) and fine (silt, clay). Coarse sediment can be easily trapped, whereas fine sediment may be difficult to remove from water because of slow settling rates. Silt and clay particles may bind together to form small bundles or aggregates as large as sand grains. Such particles also settle at somewhat faster rates, thereby providing greater opportunity to use common erosion and sediment control practices to trap the sediment in transport. Other soils consist of highly dispersed silt and clay particles that remain in suspension as discrete particles.

Sediment texture is a combination of the textures of the individual layers of eroding soils. Coarse-textured sediment may abrade equipment, bury wildlife habitat, and interfere with biological activity in environments with normally fine-textured beds. It can also cause actual physical damage to organisms (gills, guts, and protective coatings) or prevent burrowing and feeding tube formation. Fine-textured sediment may reduce light penetration by increasing turbidity, cover spawning or feeding areas, fill voids in coarse sediments used by lower order invertebrates or salmonids, and transport associated or adsorbed pollutants.

When erosion significantly declines in a watershed or river basin, a lag period occurs before the sediment concentrations in streams reflect the anticipated reductions. This is because sediment entrains throughout the landscape, from the erosion source through the first stream channel to larger channels, and is temporarily or permanently stored all along this pathway. All flood plains are made of sediment deposited by rivers and streams. Typical sediment loads from the major rivers in the United States represent only 1 percent or less of the total amount of soil erosion occurring in their basins.

Environmental damages

Irrigation systems, canals, and ditches

Numerous sources of sediment are associated with irrigated agriculture. Surface water systems with direct diversions from watercourses can cause sedimentation in the watercourse downstream from irrigation diversions. Sedimentation of irrigation laterals at the turnout is another source. Irrigation-induced erosion in the furrows is found downstream from the lateral. From the tailwater area, additional erosion and associated sedimentation occur along the return flow to the watercourse or canal. Sheet and rill erosion and associated sediment as well as ephemeral gullies can be found in sprinkler systems, particularly center pivot systems.

Reported sediment yields from furrow-irrigated fields exceed 9 tons per acre per year, with some studies reporting yields exceeding 45 tons per acre per year. Under center pivot sprinklers, yields as high as 15 tons per acre per year have been reported. In addition, sediment yields as high as 2 tons per acre per year are reported from erosion along tracks of irrigation equipment. A 1993 evaluation of 1,819 reservoirs and lakes showed a storage loss of 5 percent from sediment depletion (Atwood, 1994). However, 48 percent of these reservoirs were projected to be half full by 1993. Lost reservoir storage from sedimentation varies geographically. For example, in one study of 42 reservoirs in Iowa, Nebraska, and Missouri, 18 reservoirs lost 25 percent of their storage capacity in 11 years or less. The study did not, however, differentiate well between cropland and noncropland sources of sediment (Clark et al. 1985).

Removing sediment in impoundments may occasionally have a detrimental effect on the fine sediments that seal coarse-textured canals. The clean water releases from the structure scour the bed and sides of conveyances, thereby removing the fines from earlier direct diversions.

Floodplain sedimentation

The filling of stream channels and floodplains has turned some areas of highly productive farmlands into wetlands. This transformation occurs when excessive stream sedimentation impairs drainage of bottomland or alluvial soils. Such swamping may occur when accelerated erosion fills stream channels, which raises the water table on the bottomlands, or when modern sediment deposits form natural levees that prevent proper surface drainage.

Swamping normally occurs downstream from high sediment production areas such as mines, quarries, and critically eroding upland areas or after very large flood events. Sediment produced from these critical areas remains in the floodplains (in storage) for many years—even centuries.

Detailed national estimates of the amount of swamping damages or changes in land use from channel filling and floodplain aggradation are not available. Most reported regional swamping occurs along the Fall Line from Maryland to Georgia and within the Mississippi embayment. Swamping is also common along the Upper Mississippi Valley and adjacent lowlands and within the “Driftless” area of Wisconsin.

Soil productivity

As previously discussed, soil quality and productivity are closely intertwined with water quality. In the natural system, frequent small floods generally benefit soils on floodplains by depositing relatively small layers of mineralized fine-textured sediments on them. The infrequent large floods are responsible for channel realignments, scouring, and deposits of infertile sand and gravel layers. (Walker, 1995)

On agricultural lands, sedimentation can negatively affect productivity in two ways. First, the deposition of relatively infertile material on good agricultural land contributes to a long-term loss in yield. Second, sediment can bury growing crops or cover plant leaves with a thin film that interferes with photosynthesis and respiration. About 61 million acres of cropland are subject to sediment damage. In addition to sediment deposited on the floodplain, some deposition occurs on upland fields, but the amount of this damage has not been estimated.

Water treatment

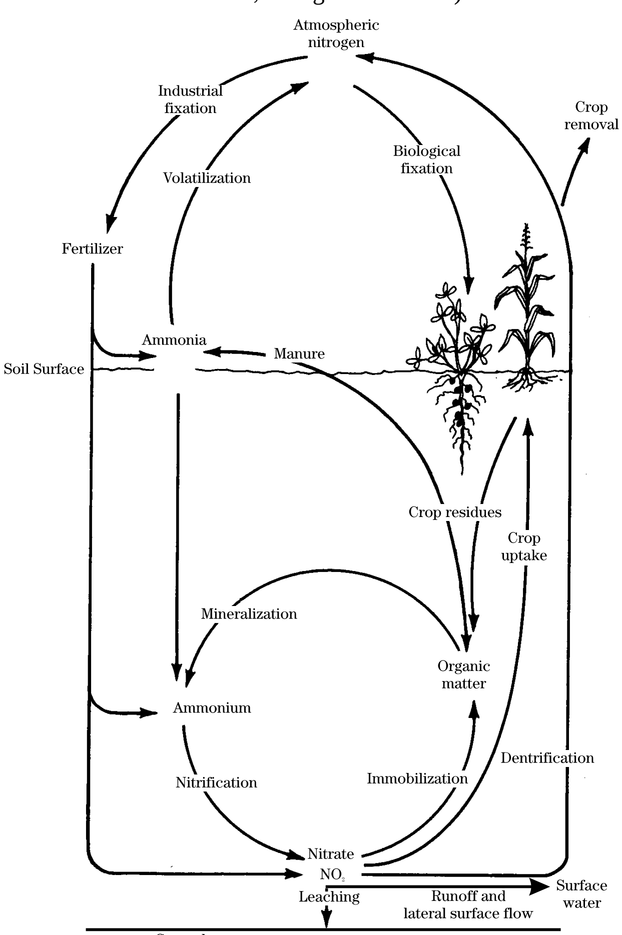
Community water systems, small water systems, and individual wells supply water to most of the U.S. population. These systems process raw water into drinking water. Sediment and its associated contaminants can substantially increase the problems and costs of providing safe drinking and processing water. Turbidity also increases the required investment and the operation and maintenance cost of the water treatment facility. Sediment basins must be built, chemical coagulants added, and filters cleaned frequently.

EPA Water Quality Criteria for finished drinking water set a maximum limit of 1 nephelometric turbidity unit (NTU; also called Jackson Units) where the water enters the distribution system. Turbidity is not only caused by sediments but also, and often significantly, by planktonic animals and plants. Average raw water turbidity for all systems has been found to be over 15 NTUs, with the average individual system turbidities ranging from 390 to .04 NTUs. (Am. WaterWorks Assoc. 1993).

Practices to reduce sediment yield

Conservation practices on agricultural land that significantly reduce sediment yield include buffer strips, filter strips, constructed wetlands, terraces, water and sediment control structures, gully plugs, diversions, and sediment basins. Because reductions in off-the-field sediment loads from conservation practices will increase streambank erosion in some areas as a result of increased hydraulic energy, streambank erosion controls and restoration techniques may be needed.

Figure 2-1 The nitrogen cycle (Natl. Res. Counc. 1993; reprinted with permission from the Pennsylvania State College of Agricultural Sciences; all rights reserved)



Nitrogen

Nitrogen (N) is an essential nutrient required for the survival of all living things[2]. It is the mineral fertilizer most applied to agricultural land because mobile nitrogen compounds are so difficult to retain in soils where plant and animal diversity is restricted and nitrogen-fixing bacteria are absent. Available soil nitrogen supplies are often inadequate for optimum crop production. Concern is mounting over agriculture’s role in delivering nitrogen into the environment.

The nitrogen cycle

Nitrogen is continually cycled among plants, soil organisms and organic matter, water, and the atmosphere (fig. 2–1). Most nitrogen in the biosphere is in the atmosphere, and much is found in water through natural aeration processes (Walker, 1995). Nitrogen enters and leaves the soil in many ways through complex biochemical transformations. The nitrogen cycle—the balance between inputs and outputs—determines the amount of nitrogen available for plant growth and the amount lost to the atmosphere and to surface and ground water.

Nitrogen taken up by plants from the soil originates from organic and inorganic forms. Organic nitrogen occurs naturally in the soil; it can also be added from manure and biological fixation from legumes (e.g., alfalfa, clovers, beans, peas). Inorganic (mineral) nitrogen includes ammonium, nitrite, and nitrate.

Most of the nitrogen in the soil is stored in soil organic matter, a key indicator of soil quality. This nitrogen is transformed through mineralization into ammonium ions (NH_4) and released into the soil. Ammonium

[2] Material selected from R.F. Follett (1994) and from National Research Council (1993).

adsorbs to clay minerals and organic matter and can be transported to surface water attached to sediment or suspended matter. Under certain conditions, ammonium can be harmful to fish and aquatic life.

Nitrification transforms ammonium ions to nitrite (NH_2) and nitrate (NH_3). Nitrate is easily absorbed by plant roots. Nitrates not absorbed by plants are free to flow into surface water or leach into ground water. Usually, nitrite does not accumulate in soil because it is rapidly transformed into nitrate.

Ammonium ions and nitrates are converted to organic nitrogen (organic N)—the form most useful to plants—through immobilization processes. These processes of mineralization and nitrification happen constantly and rapidly.

Denitrification returns nitrogen from the soil to the atmosphere by converting nitrate into nitrite and then into gases—gaseous nitrogen (N_2) and nitrogen oxides (NO_x). Nitrogen oxides may contribute to global climate changes.

The balance of these interactive processes on the various forms of nitrogen determines the amount of nitrogen available for crops and the amount lost to the environment.

The goal of nitrogen management is to reduce "the amount of residual nitrogen in the soil-crop system by bringing the nitrogen entering the system from all sources into closer balance with the nitrogen leaving the system in harvested crops . . . to reduce the losses of nitrogen to the environment" (National Research Council 1993).

Environmental impacts

Many sources of nitrogen can contribute to water quality problems. Typical point sources include human and animal waste disposal sites, industrial sites, and sites where nitrogenous materials accumulate through handling and accidental spills. In farmed areas, agricultural activities contribute heavily to nonpoint sources. For example, commercial fertilizers are used to supply additional nitrogen for crop needs. High-density animal operations are also significant agricultural sources of nitrogen. Here, large amounts of feed (containing nitrogen) are transported into the watershed from other areas, but manure is not taken out of the watershed because of high transportation costs. The result of disposing of all manure near the animal operations is that nitrogen is applied to the land in measures far exceeding crop nutrient requirements.

A primary concern about the impact of nitrogen on the environment is the possibility of nitrate leaching into ground water. This concern stems largely from potential health effects on humans and ruminant animals from drinking contaminated water (Follett and Walker, 1989). These health effects are reported to include methemoglobinemia, cancer, and other adverse conditions. Experimental evidence, however, does not show nitrate and nitrite to be carcinogenic per se, and making a scientifically reliable estimate of the human cancer risk posed by exposure to nitrate in drinking water is currently impossible.

EPA established a 10 mg/L standard as the maximum contaminant level (MCL) in drinking water. According to Fedkiw (1991), the standard was established to protect the most nitrate-sensitive segment of the population—infants under 6 months old. Until infants are about this age, bacteria in the digestive system can convert nitrate into toxic nitrite, transforming hemoglobin, which carries oxygen throughout the body, to methemoglobin, which does not carry oxygen. As the oxygen carried by the blood decreases, the body suffocates—a condition called infant cyanosis or methemoglobinemia (blue-baby syndrome). At about 6 months, an infant's stomach acidity increases to create an unfavorable environment for the bacteria causing the problem.

Clinical reports of methemoglobinemia have been virtually nonexistent in recent years. A study of Nebraska hospitals in 1988 reported that 33 cases had been encountered with no fatalities recorded. One blue-baby death reported in a highly fertilized area of South Dakota in 1986 was tentatively linked to fertilizer but also to infant formula mixed with drinking water possibly contaminated from a leaky septic system.

Nitrogen in ground water

Ground water withdrawals provided over 20 percent of freshwater taken from the natural system for off-site uses in the United States in 1990 (Walker, 1995). Ground water accounted for 51 percent of all U.S. drinking water in 1990, and that figure rises to 96 percent in all rural areas and among those served by private resources (Job, 1995).

Nitrate is the primary form of nitrogen leached to ground water. It is totally soluble and moves freely in solution (i.e., leaches) through most soils. Nitrate is repelled rather than attracted by clay mineral surfaces in soil. Other forms of nitrogen are less likely to leach. For example, ammonium (NH4+) does not easily leach because it is strongly adsorbed by many kinds of soils. Nitrate appears widely in ground water because of its high solubility, mobility, and easy displacement by water. Influences on dissolved nitrate transport vary substantially at different locations. A single wormhole or decayed root channel can significantly raise the soil infiltration rate when water is ponded over it. Therefore, leaching velocities are not spatially uniform, even when water is applied uniformly over an area, such as by rainfall or sprinkler irrigation.

A recent USGS study that will be cited at length in Chapter 5, analyzed ground water depth below land surface, hydrogeologic setting, soil hydrologic group, depth to water, land use, and type of agriculture as factors affecting nitrate concentration in ground water (Mueller et al. 1995). It found that nitrate concentrations in ground water

- decrease quickly to depths of about 150 feet, then decrease more slowly;
- were highest in unconsolidated sand and gravel aquifers;
- were highest beneath the two well-drained soil hydrologic groups;
- were significantly higher beneath agricultural land compared to other land uses; and
- were higher beneath cropland than below pasture or woodland.

Although elevated nitrate concentrations are most often observed at shallow water-table depths, long-term increases in deeper wells are possible. Current inputs of nitrate can take many years to reach deep aquifers, since the general flow direction in most aquifers is horizontal not vertical; the movement is slow; and there is little mixing of contaminated with uncontaminated ground water. Given this slow movement and lack of dilution, contamination may persist for decades or centuries, even if nitrate sources are eliminated. Simultaneously, ground water reclamation remains technically and economically very difficult if not impossible (Keeney, 1986).

Nitrate leaching can be minimized in two ways. First, the crop's ability to compete with processes that allow excess plant-available nitrogen to be lost from the soil-plant system can be optimized. Second, the rate and duration of the loss processes themselves can be directly lowered. The first approach requires assuring vigorous crop growth and nitrogen assimilation by applying nitrogen in phase with crop demand and taking credits for nitrogen released from plowed-under legumes. The second approach includes the use of nitrification inhibitors or delayed-release forms of nitrogen to cut potential leaching losses. In addition, realistic crop yields must be selected as goals.

Ground and surface water are interconnected. Much ground water—about 40 percent of streamflow nationally—is discharged to rivers and streams; but it is also discharged to lakes, reservoirs, estuaries, and coastal waters (Job, 1995). While some transfer of water flows in the downward direction, especially in aquifers that are being water-mined, the general flow in most aquifers is more horizontal than vertical. Flow velocities in unconfined and semiconfined aquifers are generally higher near the top of the aquifer than near the bottom.

Runoff and surface water

The dominant factors in the loss of dissolved nitrogen in runoff are the amount and timing of rainfall and soil properties. Soils with low runoff potential usually have high infiltration rates even when wet. They commonly consist of deep, well-drained to excessively drained sands or gravels. In contrast, soils with high runoff potential have one or more of the following characteristics:

- very slow infiltration rates when thoroughly wetted and high clay content, possibly with high swelling potential;
- high water tables;
- a claypan or clay layer at or near the surface;
- shallowness over nearly impervious material.

Soils with high runoff potential combined with much precipitation are especially conducive to surface runoff losses. Steeper slopes increase the runoff amount and velocity; depressions, soil roughness, and vegetative cover or crop residues reduce runoff by improving water infiltration.

Soils under conservation tillage or no-tillage often have a higher dissolved nitrogen concentration in surface runoff than soils under conventional tillage. Reasons may include incomplete incorporation of surface-applied fertilizer, dissolved nutrient contributions from decaying crop residues, and higher dissolved nitrogen concentration in the surface soil. The latter is caused by residue accumulation and decomposition (McDowell and McGregor, 1984).

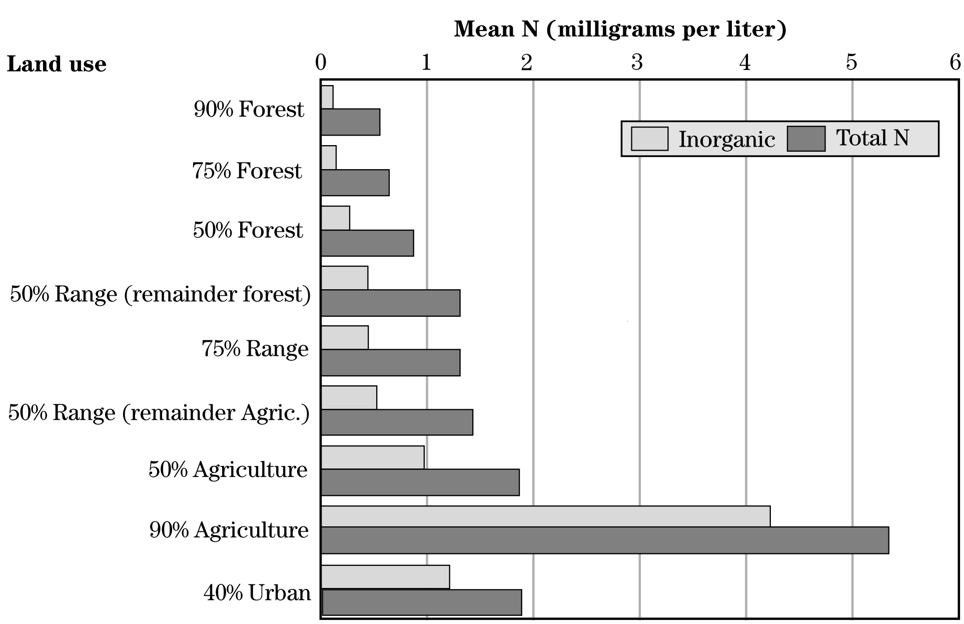
Much of the nitrogen that enters lakes and rivers is associated with eroding sediments and eroding soil organic matter, or it is dissolved in surface runoff. The water that runs over the soil surface during a rainfall or snowmelt event may have a high concentration of organic nitrogen attached to suspended particles, but it is typically low in nitrate concentration.

Omernik (1977) summarized stream water-quality data from 904 watersheds where nonpoint source land uses were predominant. He found that inorganic nitrogen concentrations were directly related to the amount of the watershed used for agriculture (fig. 2–2).

When waters become too enriched by nutrients, the aquatic environment can become eutrophic. This condition produces luxuriant growths of algae and macrophytes to levels that can choke navigable waterways, increase turbidity, and depress dissolved oxygen concentrations. When a large mass of algae dies and begins to decay, it depletes the oxygen dissolved in water and produces certain toxins; both conditions can kill fish. Further, the nutrient status of various algae species can vary from lake to lake, and even from different areas and depths of the same lake on the same day. Excess algal growth can create obnoxious conditions in ponded waters, cause serious taste and odor problems, and increase water treatment costs by clogging screens and requiring more chemicals.

Sawyer (1947) was the first to propose quantitative guidelines for lakes. He suggested that 0.3 mg/L of inorganic nitrogen and 0.015 mg/L of inorganic phosphorus are critical levels above which algal blooms can normally be expected in lakes. Nevertheless, EPA has not developed nutrient criteria or recommended methodologies for protecting waterbodies from exces-

Figure 2-2 Land use and mean organic and total nitrogen concentrations in stream data (Omernik, 1977)



sive nutrient loading. National criteria for nitrate, nitrite, and ammonia in water supplies are established to protect human health and aquatic life; they do not address eutrophication or impairments to recreational uses. Under natural conditions, nitrate and nitrite occur in moderate concentrations and are not generally harmful to most aquatic life. Ammonia, on the other hand, is highly toxic to aquatic organisms. Exposure to ammonia can produce chronic toxic effects, including reduced hatching success and growth rates, and developmental or pathological changes in gill, liver, and kidney tissues (U.S. Environmental Protection Agency, 1986).

Management to improve nitrogen use efficiency

Systematic data on nitrogen's availability and future use under alternative agricultural management systems are not readily available for the large variety of U.S. soils and climates. However, opportunities do exist in agricultural management to reduce nitrogen losses from the crop-soil system.

Fertilizing crops for nitrogen uptake at or near the point of maximum yield is generally an economically and environmentally acceptable practice. Using less nutrients to achieve the same per unit crop yield improves efficiency. Increasing nitrogen efficiency means installing practices that lower the rate and duration of nitrogen loss processes. One approach is to decrease the soil's total residual nitrogen. A second approach is to keep residual nitrogen in the system by curtailing leaching, runoff, erosion, and volatilization or by increasing the mass of inputs immobilized or degraded in the soil-crop system.

Current practices generally involve supplying crop-nitrogen needs in one to three fertilizer applications. Nitrogen fertilizers in common use include anhydrous ammonia, which converts quickly to ammonium hydroxide; urea; ammonium nitrate; animal manure, and green crop plowdowns. The conversion of these forms to nitrate begins almost immediately but may take days or weeks before nitrate levels exceed the ability of plants and organic matter to capture and use them. Once these levels are reached, any nitrate not removed from the root zone becomes a potential leaching source.

Synchronizing the nitrogen supply with crop needs will reduce leaching below the crop's root zone. However, producers may be applying nitrogen at higher rates than needed for optimal crop growth as insurance against making a wrong decision that would lead to lower yields. Their notion of economically optimal application rates is closely related to optimal rates for crop growth—but these rates are not necessarily the same.

Improved nitrogen-use efficiency requires that soil nitrogen availability and crop nitrogen requirements be synchronized for realistic yield goals. Generally, 95 percent of a five-year yield average is a realistic goal, although cultural practices, soil water status, crop pests, and many other factors that affect crop nitrogen uptake will complicate management decisions. Genetic selection for improved nitrogen efficiency in crops such as corn and sorghum may reduce nitrogen requirements.

Explicit accounting by producers for all nitrogen sources to a crop is a valuable framework to quantify and examine nitrogen inputs and losses for agricultural production systems. One method of altering the release of nitrogen from soluble materials has been to coat water-soluble granular nitrogen fertilizer with less water-soluble materials to retard entry of water into the particle and the outward movement of nitrogen. Sulfur-coated urea, for example, is a recently developed product with the characteristics of slow nitrogen release, relatively low cost, and ease of handling.

Conservation tillage

Use of conservation tillage or reduced tillage (including no-till) continues to increase. Management systems that maintain crop residues at or near the soil surface have several attractive features, including less on-farm energy use, more available soil water, and reduced soil erosion.

Conservation tillage practices exhibit a variety of influences on the movement of nitrogen from the soil-plant system into the environment. Conservation tillage can reduce nitrogen losses associated with soil erosion and surface runoff. On sloping lands, these losses are usually a larger component of the total load to the downstream environment. The smaller component is leaching. Conservation tillage provides a wetter, cooler, more acidic, less oxidative soil environment. Under such conditions, ammonification and denitrification processes may be favored over nitrification. For nitrate already present, the leaching potential may be greater under conservation tillage because more undisturbed soil macropores exist for nitrate and water movement.

Increased water flow into and through the root zone has been observed under no-till compared with conventionally tilled soils. This higher flow has been attributed to reduced water evaporation because of surface residues and to increased numbers of undisturbed channels (made by earthworms and old roots) continuous to the soil surface. The surface mulch enhances the environment for earthworms, and the lack of tillage preserves existing channels for several years.

We still have much to learn about how residue management practices affect nutrient transport from agricultural fields. Follett et al. (1987) estimated that compared to conventional tillage, conservation tillage reduces by nearly half the amount of organic nitrogen carried by water and its associated sediments. No-tillage decreases the amount further. One can assume that applied fertilizer nitrogen sorbed to soil organic matter responds likewise.

Rotations, cover crops, and nitrogen–scavenging crops

Monocultures of grain crops such as corn and wheat require high inputs of fertilizer nitrogen. These inputs can be reduced by rotating with crops that require less nitrogen or biologically fix atmospheric nitrogen. Winter cover crops can absorb both nitrate and available water during the fall, winter, and spring, thereby decreasing the potential of nitrogen to leach. When the cover crop is returned to the soil, some of the sorbed nitrogen is then available to the following crop. Both legumes and nonlegumes are used as deterrents to nitrogen leaching. Annual crops, such as rye, can be effective in scavenging excess available nitrogen within crop rooting zones. Legumes in symbiosis with nitrogen fixing bacteria are both users and producers of nitrogen. They can be used as substitutes for purchased fertilizer and as scavengers of applied nitrogen.

Because nitrite and nitrate are highly water soluble, crop irrigators can affect nitrogen movement by switching to more efficient techniques to get the proper amount of water and nutrients to plant roots. These systems and techniques include

- testing water for nitrogen content,
- calibrating water application equipment,
- converting to irrigation systems (i.e., trickle irrigation or low pressure sprinkler irrigation) that allow more precision in the amount and distribution of water applied,
- leveling land to minimize runoff and improve irrigation efficiency, and
- fertigation.

Filter strips

Vegetative filter strips, buffer strips, and vegetated riparian zones trap sediment, organic matter, and other pollutants from runoff and waste waters. Excess runoff from terraces is frequently diverted to a strip. Both the flow velocity and transport capacity of the runoff are immediately lowered. The sediment and its associated pollutants are then removed by filtration, deposition, infiltration, sorption, decomposition, and volatilization.

The effectiveness of filter strips in removing sediment and particulate nitrogen is well established. Less certain is their effectiveness for removing soluble nitrogen in runoff. Uptake by filter strip vegetation of mineral nitrogen transported by runoff may occur during active growth with less uptake during other times of the year. Some denitrification may also occur during active growth. Scavenging of nitrogen from underground water and the vertical horizon by riparian vegetation, especially by deep-rooting plants, may be important for removing dissolved nitrogen in surface and subsurface flows before the nitrogen is transported into streams and lakes.

Source areas and in-field targeting

Water quality impact zones for nitrogen are wells, ground water supplies, streams, and surface water bodies. Because 96 percent of rural inhabitants and much livestock consume ground water, high nitrate concentrations are a concern. However, in many areas, nitrate is of far less significance than other constituents, such as radon, iron, manganese, copper, lead, sulfates, carbonates, sodium, and pathogens (Walker, 1995). Dilution and the well’s position relative to nitrate source areas can greatly affect the impact of nitrate on ground water. Streamflow that mixes ground water discharge and surface runoff from different land uses and time periods may produce lower and more stable nitrate concentrations.

Because the subsurface system's structure, function, and efficiency are generally large, lacking in uniformity, and often poorly understood, we can more easily focus on source areas. The source area is a bounded area or volume within which one or a set of related processes dominates to provide excessive production (source), permanent removal (sink), detention (storage), or dilution of nitrate.

Some practices are particularly effective in reducing nitrogen movement to ground water; for example, repair or permanent sealing of abandoned wells, wells with cracked casings, and shallow, hand dug, poorly cased wells.

As previously noted, although systematic data on production practices, input use, and management systems are insufficient for many assessments, the quantity and quality of soil and climate data and assessments of nitrate concentrations in various aquifers are increasing. Statistical techniques and simulation models used in conjunction with geographical information systems technology show promise in identifying and assessing nitrate leaching across regions. Models such as the Nitrate Leaching and Economic Analysis Package (NLEAP; see Shaffer et al. 1991) and the Erosion Productivity Impact Calculator (EPIC; see Williams, 1989) use farm management, soil, and climate information to estimate nitrate runoff and leaching.

Various methods based on complex simulation models can be used to estimate a farm field's sensitivity to nitrogen leaching and runoff. Methods include a System of Early Evaluation of the Pollution Potential of Agricultural Groundwater (SEEPPAGE), the Phosphorus Index, and Farmstead Assessment System (FARM*A*SYST). Each method or tool must be tailored for local conditions. Furthermore, since water is necessary to move nutrients overland and through the soil/geologic profile, precipitation events and patterns may be the overriding factor in nitrogen movement.

As technology continues to improve, the targeting of improved practices, farm enterprises, fields, and even areas (hot spots) within a field should make it easier to reduce losses of nitrogen to the environment.

Phosphorus

Phosphorus (P) is an essential element for plant growth and increased crop yields.[3] However, because soil phosphorus is commonly immobilized in forms unavailable for crop uptake, phosphorus amendments—mineral fertilizer or animal manure—are needed to achieve desired crop yields. Since phosphorus is often bound more tightly to soils than nitrogen, a different approach to control agricultural phosphorus losses is required (National Research Council 1993). Despite its benefit to crop production, phosphorus becomes a pollutant when it enters surface water in substantial amounts.

Some phosphorus compounds ingested in high level concentrations can be highly toxic to humans. Others can be caustic on skin contact. Phosphorus is not believed to be toxic at concentrations normally found in food and water, partly because most naturally occurring phosphates are comparatively low in solubility.

Excessive phosphorus concentrations in surface water can accelerate eutrophication, resulting in increased growth of undesirable algae and aquatic weeds. This growth can impair water use for industry, recreation, drinking, and fisheries. Although nitrogen and carbon are also associated with accelerated eutrophication, most attention has focused on phosphorus as the limiting element. Because it is difficult to control the exchange of nitrogen and carbon between the atmosphere and a waterbody and because of the fixation of atmospheric nitrogen by some blue-green algae, phosphorus control is seen as the primary way to reduce the accelerated eutrophication of surface water.

The goal of phosphorus management is "to prevent the buildup of excess phosphorus levels in soil while providing adequate phosphorus for crop growth. . . . [This] should be a fundamental part of programs to reduce phosphorus loading to surface water" (National Research Council 1993). To develop agronomically and environmentally sound agricultural systems for phosphorus, we need to understand the forms of phosphorus in soils, the dynamics of cycling between forms that differ in bioavailability (availability for uptake by plants and aquatic biota), and the processes

[3]Material adapted from Sharpley (1994).

controlling the removal and transport of soil phosphorus by runoff.

The phosphorus cycle

When added to the soil-crop system, phosphorus—like nitrogen—goes through a series of transformations as it cycles through plants, animals, microbes, soil organic matter, and soil minerals. Because phosphorus is bound to most soils, only a fraction is available to plants.

Phosphorus in soil is found in two forms—organic and inorganic (mineral). Although dynamic transformations between forms occur continuously, 50 to 75 percent of the phosphorus in most soils is inorganic.

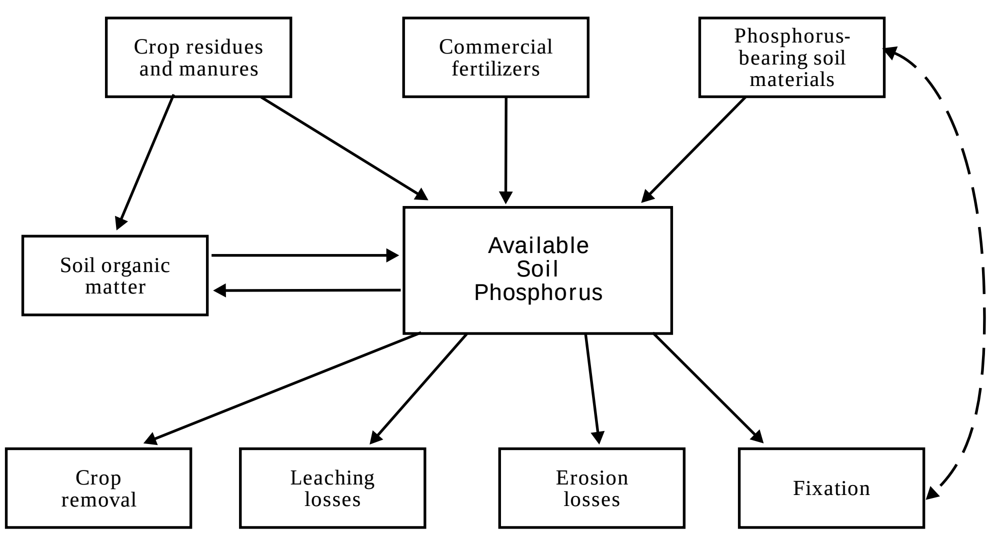
Organic phosphorus is broken down by soil microbes in plant residue, manure, and other organic material. Much of the phosphorus is taken up by the microbes; as the microbes die, the phosphorus is transferred to the soil. The soil humus holds a considerable amount of organic phosphorus, a portion of which is released each year as the materials decay. Phosphate ions, released from decaying organic phosphorus or added in fertilizers containing inorganic phosphorus react with soil minerals; they become immobilized and unavailable for plant growth (fig. 2-3).

Phosphorus is lost from the land in soluble form (soluble phosphorus) through subsurface flow, surface runoff, and leaching—although in most areas leaching to ground water is not a problem. Most phosphorus lost from croplands—75 to 90 percent—is lost through runoff or through binding to eroded organic matter and to eroded sediment particles (particulate phosphorus). Some is also lost as soluble phosphorus. When delivered to surface water, soluble phosphorus can stimulate eutrophication. Particulate phosphorus is a long-term source of phosphorus. From grassland or forest land, runoff carries little sediment and is therefore dominated by the dissolved form.

Phosphorus bioavailability and mobility are generally greater under aerobic conditions in wetland soils than in dryland soils. This enhances the potential phosphorus movement in drainage and runoff water from wetland soils. Wetland soils can function as sinks and sources of phosphorus (Reddy et al., in press; Richardson, 1985).

Phosphorus is added to the soil from crop residue, manure, synthetic fertilizer, and phosphorus-bearing minerals. Synthetic fertilizers add the most phosphorus to U.S. croplands—some 79 percent of the total

Figure 2-3 The phosphorus cycle (Natl. Res. Counc. 1993)



input. Depending on the area, the addition of phosphorus from manures can also be large. The amount of phosphorus immobilized in mineral or organic matter varies, depending on the location and type of soil. The potential for phosphorus buildup over time, however, is large and increases the amount lost through runoff.

Phosphorus is removed from the soil with the harvested crop. The difference between the input and output of phosphorus is called the phosphorus mass balance. This balance is immobilized in the soil, bound to organic matter, or transported to surface or shallow subsurface waters.

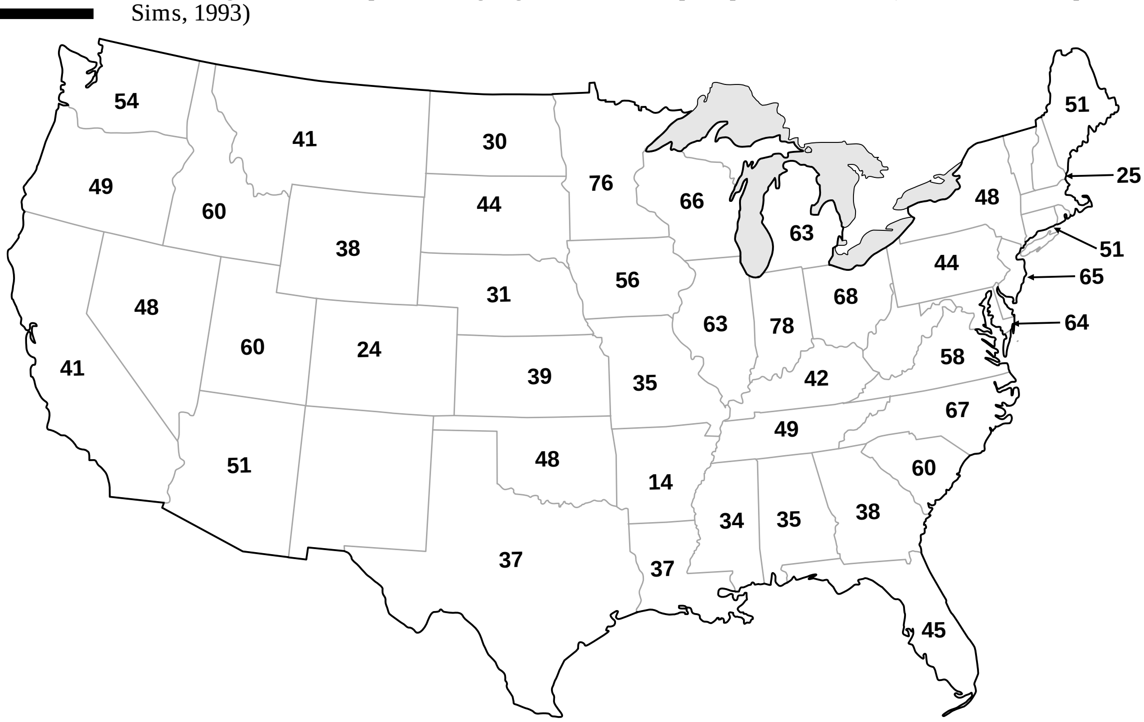
Although phosphorus use in crop production is relatively high (56 to 76 percent), animals use very little (10 to 84 percent). Since 76 to 94 percent of total crop production is fed to animals, phosphorus efficiency for all agriculture is low (11 to 38 percent), and clearly affected by use in confined animal operations (Isermann, 1990).

Soil phosphorus

The phosphorus level in surface soil determines the phosphorus loads in runoff and the proportions of soluble and particulate phosphorus lost. Increased residual levels in the soil lead to increased loadings to surface waters. Although phosphorus management and erosion control are important tools for reducing the phosphorus loss from croplands, reducing the phosphorus buildup in soil is also necessary. Continuing, long-term phosphorus applications can raise phosphorus levels above those required for optimum crop yields. Once phosphorus levels become excessive, the potential for loss in runoff and drainage water is greater than any agronomic benefit of further applications.

In recent years, the acres of soils with phosphorus levels exceeding the levels required for optimum crop yields have increased in areas with intensive agricultural and livestock production. Efficient use is a concern, particularly in areas that produce manure in confined animal operations. As manure applications are frequently made based only on the nitrogen needs of the plant, phosphorus applications may be excessive and lead to elevated phosphorus levels in the soil. This practice is a potential problem especially at sites that already have high available phosphorus levels. However, basing manure application on phosphorus rather than nitrogen would complicate disposal

Figure 2-4 Percentage of soil samples testing high or above for phosphorus in 1989 (Potash and Phosphate Institute, 1990; Sims, 1993)



problems since the *per acre* application rates would have to be reduced, and the *number of acres* required for manure disposal would have to increase.

High phosphorus levels are a regional issue. For example, most Great Plains soils still require fertilizer phosphorus for optimum crop yields (fig. 2-4). Many soils with high phosphorus levels are located near sensitive waterbodies; for example, Great Lakes, lakes in Florida and New England, and Chesapeake Bay.

Table 2-1 Nonpoint sources of phosphorus

Terrestrial Sources

Runoff from noncultivated, "pristine" land*
- soil erosion
- animal excreta
- plant residues

Runoff from cultivated land**
- soil erosion
- fertilizer loss
- animal excreta
- plant residues
- sewage sludge

Runoff from urban land**
- soil erosion
- septic tanks
- domestic waste

Atmosphere (cultural**; natural*)
- wet precipitation
- dry precipitation

Aquatic Sources

Lake sediments**
- bottom sediments
- resuspended sediments

Biological**
- fauna and flora

Source: Adapted from Sharpley, 1994.

* very difficult to reduce
** difficult to control

Sources and transport

Table 2-1 summarizes the main nonpoint sources of the phosphorus load to water bodies. The amount transported in runoff from rural uncultivated or "pristine" land, considered the background or ambient loading, is difficult to reduce and may be sufficient to cause eutrophication. Assessing the impact of agricultural management on phosphorus loss in runoff is also difficult since little quantitative information is available on background losses of phosphorus before cultivation. Consequently, quantifying any increase in phosphorus loss following cultivation is difficult. These problems result mainly because water quality monitoring studies are expensive and labor intensive. In addition, these studies are site specific and impossible to replicate because of the spatial and temporal variations in climate, soil, and agronomy. Despite these problems, we can make some generalizations from published studies concerning the effect of agricultural management on phosphorus transport in runoff.

As forested land in a watershed gives way to agriculture, the loss of phosphorus in runoff may increase (fig. 2-5). The phosphorus loss from forested land tends to be similar to that found in subsurface or base flow from agricultural land (Ryden et al. 1973). In general, forested watersheds conserve phosphorus, with phosphorus input in rainfall usually exceeding outputs in streamflow (Schreiber et al. 1976). As a result, forested areas are often used as buffers or riparian zones along streams or around water bodies to reduce phosphorus inputs from agricultural land (Lowrance, Leonard, and Sheridan, 1985; and Lowrance et al. 1984). However, the potential loss of phosphorus from agricultural land largely depends on the relative importance of surface and subsurface runoff in the watershed.

Phosphorus losses in surface runoff depend on the rate, time, and method of fertilizer application; amount and timing of rainfall after application; and vegetative cover. Several studies show that the proportion of applied phosphorus transported in runoff is generally greater from conventionally tilled than from conservation-tilled cropland. However, applying fertilizer phosphorus to no-till corn reduces particulate phosphorus transport (McDowell and McGregor, 1984), probably because of the increased vegetative cover from fertilization. Losses of applied phosphorus in runoff are generally less than 5 percent, unless rainfall immediately follows application. One or two severe events can cause most of the annual runoff in a watershed—75 percent or more (Edwards and Owens, 1991; Smith et al. 1991), and these few events can contribute over 90 percent of annual phosphorus loads.

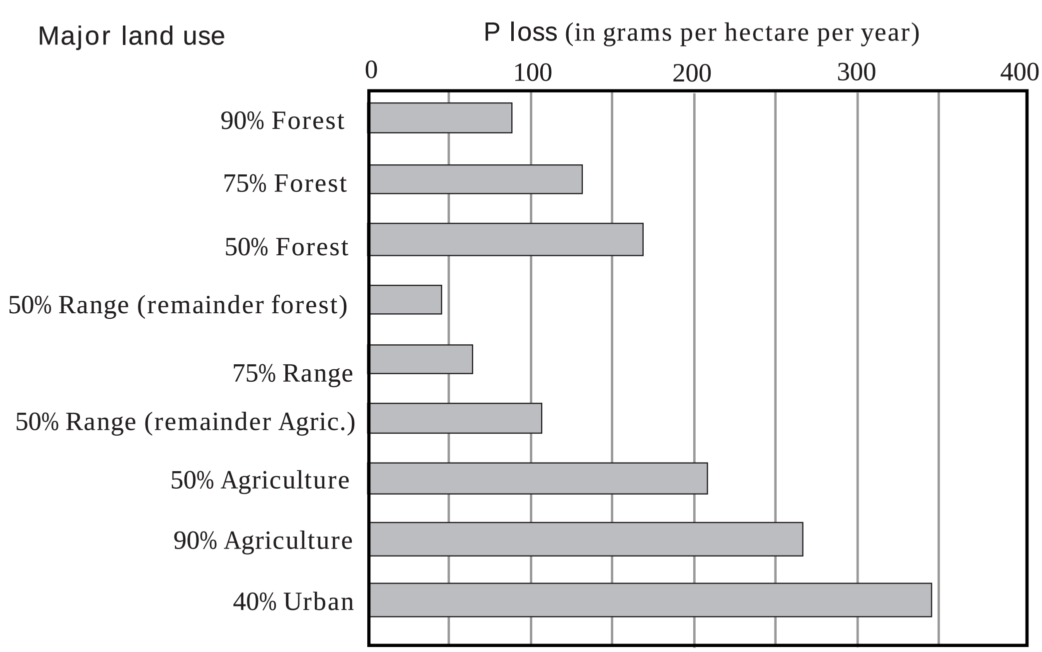
Phosphorus loss by subsurface dispersion—whether through tile drainage or natural subsurface flow—is appreciably lower than runoff loss. In general, phosphorus concentrations and losses through natural subsurface flow are lower than through tile drainage.

The transport of phosphorus in runoff and erosion is the primary flow of phosphorus between ecosystems. However, internal secondary phosphorus flows can occur in conservation tillage systems when crop residue is left in place to minimize evaporation and erosion. Similarly, a cover crop included in a rotation is killed before maturity to prevent it from competing for water and light with the following cash crop. The cover crop residue left on the surface or occasionally plowed into the soil may affect phosphorus levels as it decomposes. External secondary phosphorus flows also include the transfer of phosphorus in grain or hay from the area of production to confined animal operations in geographically distant regions. Although we have little information on their relative magnitude, secondary flows of phosphorus may be important in developing sustainable agricultural systems.

Environmental impacts

Since phosphorus is generally not toxic to major cash crops, its negative impacts on the terrestrial environment are limited. The judicious use and management of fertilizer phosphorus may reduce phosphorus enrichment of agricultural runoff through increased crop uptake and vegetative cover (Sharpley and Smith, 1991). Similarly, if phosphorus applications increase crop productivity, then erosive marginal lands may be taken out of production without changing yield goals. Carefully managed manure applications on marginal lands can increase grass and crop yields and stocking rates for pasture.

Figure 2-5 Phosphorus loss in runoff as a function of land use in the United States (adapted from Omernik, 1977)



Transport of phosphorus from terrestrial to aquatic environments accelerates eutrophication, which leads to increased growth of undesirable algae and aquatic weeds, oxygen shortages, and subsequently to problems with fisheries, and water for recreation, industry, or drinking. Massive surface blooms of cyanobacteria (blue-green algae) lead to fish kills, make drinking water unpalatable, and contribute to the formation of trihalomethane during water chlorination (Kotak et al. 1994). Consumption of algal blooms or of the water-soluble neurotoxins and hepatotoxins released when the algae die can kill livestock and may pose a serious health hazard to humans (Martin and Cooke, 1994). Advanced eutrophication of lakes increases the rough fish population relative to desirable game fish.

Banning the use of phosphate detergents in the Great Lake States greatly reduces point source loads, and that ban has been the single most effective remedial action to enhance the quality of Lake Erie (Walker, 1995). Reducing phosphorus inputs to lakes may not always achieve expected water quality improvements, however, because other sources such as rainfall continue to contribute phosphorus inputs. (Elder, 1975) estimated that rainfall phosphorus may account for up to 50 percent of the phosphorus entering Lake Superior. Lake enrichment in Ontario (Schindler and Nighswander, 1970) has also been attributed to rainfall phosphorus. The release of phosphorus from sediment can sustain the growth of aquatic biota for several years after its deposition (Jacoby et al. 1982).

Management to reduce negative impacts of phosphorus use

Although producers have generally been able to reduce the transport of phosphorus from agricultural land, less progress has been made in minimizing soil phosphorus buildup. Phosphorus-sensitive areas and phosphorus sources within watersheds need to be identified.

Phosphorus sources and in-field targeting

Rapid chemical extraction procedures are used to measure phosphorus in soil. Such tests make timely and cost-effective recommendations possible. Even so, as we move from agronomic to environmental concerns, the accuracy of operational soil test methods for estimating phosphorus forms important to eutrophication is limited. Nevertheless, recent research has shown that soil test phosphorus is correlated with several parameters needed to assess nonpoint source pollution (Sims, 1993; Wolf et al. 1985).

Several states have attempted to identify a soil test level at which fertilizer or manure applications must be changed to reduce the potential for phosphorus loss in runoff (table 2-2). At certain levels, it would require reduced or no manure and sludge application and the development of alternative end uses.

Soil testing alone cannot assess the significance of an individual site or watershed in surface water eutrophication. Testing must be complemented with assessments of the site’s drainage, runoff, and erosion potential and with management factors that affect the site’s vulnerability for phosphorus transport. For example, adjacent fields may test similarly for soil phosphorus but differ in their susceptibility to runoff and erosion because of contrasting topography or management; therefore, they should have different phosphorus recommendations. An indexing system developed to identify the soils most vulnerable to phosphorus loss in runoff assigns weights to site characteristics (Lemunyon and Gilbert, 1993). Factors include soil erosion, runoff class, soil phosphorus test, phosphorus fertilizer application rate and method, and organic phosphorus source rate and method. The index sums the weights and specifies the site’s vulnerability.

Remedial strategies

To manage phosphorus sources efficiently, fertilizer application and placement should be based on eutrophic rather than agronomic considerations. On sites with high available soil test phosphorus, applications should be limited to crop needs or eliminated. Placing phosphorus below the soil surface, away from the zone of removal in runoff, will reduce the potential for loss. Periodic plowing of no-till soils may also be desirable to redistribute surface phosphorus accumulations throughout the root zone.

Best management practices that offer no-till residue management guidelines may conflict with recommended subsurface phosphorus applications. Residue management systems that require landowners to maintain high levels of residue cover, particularly under no-till systems, may need to be modified to allow subsurface application or knifing of phosphorus fertilizer or manure to minimize potential phosphorus loss in runoff.

Table 2-2 Soil phosphorus interpretations and management guidelines

State	Critical Value	Management Recommendation	Rationale
Arkansas	150 mg kg^{-1} Mehlich 3P	At or above 150 mg kg^{-1} STP: 1. Apply no P from any source. 2. Provide buffers next to streams. 3. Overseed pastures with legumes to aid on P removal. 4. Provide constant soil cover to minimize erosion.	CV: data from Ohio with sewage sludge. MR: reduce P levels and minimize movement of P from field.
Delaware	120 mg kg^{-1} Mehlich 1 P	Above 120 mg kg^{-1} STP: Apply no P from any source until STP is significantly reduced	CV: greater P loss potential from High P soils. MR: protect water quality by minimizing further P accumulations.
Ohio	150 mg kg^{-1} Bray P1	Above 150 mg kg^{-1} STP: 1. Institute practices to reduce erosion 2. Reduce or eliminate P additions.	CV: greater P loss potential from high P soils as well as role of high soil P in zinc deficiency. MR: protect water quality by minimizing further P accumulations.
Oklahoma	130 mg kg^{-1} Mehlich 3 P	30 to 130 mg kg^{-1} STP: Half P rate on >8% slopes. 130 to 200 mg kg^{1} STP Half P rate on all soils and institute practices to reduce runoff and erosion. Above 200 mg kg^{-1} STP: P rate not to exceed crop removal	CV: greater P loss potential from high P soils. MR: protect water quality, minimize further soil accumulation, and maintain economic viability.
Michigan	75 mg kg^{-1} Bray P1	Above 75 mg kg^{-1} STP: P application must not exceed crop removal. Above 150 mg kg^{-1} STP: Apply no P from any source.	CV: minimize P loss by erosion or leaching in sandy soils. MR: protect water quality and encourage wider distribution of manures.
Wisconsin	75 mg kg^{-1} Bray P1	Above 75 mg kg^{-1} STP: 1. Rotate to P demanding crops. 2. Reduce manure applications rates. Above 150 mg kg^{-1} STP: Discontinue manure applications.	CV: at that level, soils will remain non-responsive to applied P for 2-3 years. MR: Minimize further P accumulations.

Source: Sharpley, 1994.
CV represents critical value rationale and MR, management recommendation rationale.
SPT = Soil Test Phosphorus
mg kg^{-1} = milligram per kilogram
Mehlich 3P, Bray P1 are laboratory tests used to determine STP levels.

Erosion and runoff loss may be reduced by increasing vegetative cover through conservation tillage. However, losses of dissolved and bioavailable phosphorus can be greater from no-till than from conventional till practices. Accumulated crop residues and added phosphorus at the soil surface would be decreased by tillage. In assessing effectiveness, such water quality tradeoffs must be weighed against the potential benefits of conservation measures.

Additional measures to minimize phosphorus loss by erosion and runoff include buffer strips, riparian zones, terracing, contour tillage, cover crops, and impoundments or small reservoirs, though these practices are generally more efficient at reducing particulate than dissolved phosphorus. Several studies have indicated little decrease in lake productivity with reduced phosphorus inputs following implementation of conservation measures (Gray and Kirkland, 1986).

Although phosphorus losses in runoff are generally less than 5 percent of applied phosphorus, concentrations of dissolved phosphorus (DP) and total phosphorus (TP) often exceed critical values associated with accelerated eutrophication (0.05 and 0.1 mg/L) set by EPA in 1976. This finding is true even for unfertilized native grass watersheds (Sharpley et al. 1986). Phosphorus inputs in rainfall also contribute to freshwater eutrophication. Thus, the management measures recommended here may not reduce phosphorus losses in runoff from cultivated land to critical values. This situation emphasizes the need to target remedial measures on source areas where the potential for phosphorus loss is greatest. Further, the critical level approach should not be used as the sole criterion in quantifying permissible levels of phosphorus loss in runoff. A more flexible approach advocated by limnologists considers the complex relationships between phosphorus concentration and the physical characteristics of affected watersheds (runoff and erosion) and waterbody (mean depth and hydraulic residence time) on a site-specific and recognized need basis.

Phosphorus from animal manures in barnyards and feedlots may be delivered to surface or ground water. Practices to control this runoff include water diversions and roof runoff systems, settling basins, earth shaping, filter strips, sewage waste lagoons, and waste holding pits. Preventing animal access to streams and lakes and providing animal watering facilities away from the water are a key means of reducing phosphorus loading.

Sediment control basins may capture appreciable quantities of phosphorus attached to sediment and retard water flow. Constructed wetlands can also retard water flow and allow aquatic vegetation to take up phosphorus. If the aquatic vegetation is harvested, then the overall mass of phosphorus can be greatly reduced.

Management measures to address manure disposal are often expensive to the producer. Overcoming the economic restrictions on moving manure from confined livestock operations to greater cropland acreage is difficult. Cooperatives that can cost-effectively compost and compact manure are being formed. Alternative manure management systems, such as centralized storage and distribution networks, regional composting facilities, and pelletizing operations to produce a value-added processed manure for wide distribution, are being developed. Manure storage allows for flexibility in timing application. Nevertheless, current technology will not permit producers to hold an unlimited number of animals in a small region without impacts on water quality. Institutional innovations are increasingly sought to deal with this issue. Many States currently require new animal facilities that exceed a certain size to have an appropriate waste management plan.

Consequently, efforts to minimize phosphorus transport from terrestrial to aquatic environments and thus slow down eutrophication must identify the phosphorus sources that present the greatest risk to lakes and target cost-effective remedial strategies. In confined animal operations, innovative measures to transport manure for greater distances must be developed and adopted and alternative end-uses must be found. Finally, the efficient transfer of research technology to the land user is crucial to any water quality improvement strategy. Effective implementation should include education programs to persuade water users that treating the symptoms of eutrophication rather than controlling nonpoint sources is harder and more expensive in the long term.

Pesticides

Pesticides are used to protect food and fiber from damage by weeds, insects, diseases, nematodes, and rodents. This section discusses pesticide and soil properties that help explain the movement of pesticides through the environment.

Even as today's chemically intensive agriculture is credited with providing abundant low-cost supplies of food and fiber, it is also blamed for creating a water quality problem. The nation's awareness that agricultural chemicals wash into streams and rivers and seep into ground water followed the development of procedures for sensitive chemical analysis. These procedures not only heightened our awareness of environmental contamination; they also contributed to our uncertainty about the danger posed by contamination. A 1985 opinion poll (Batie et al. 1986) found that nationwide only 23 percent of the respondents were willing to accept that drinking water was safe if it met government standards but still contained small amounts of chemicals.

Concerns about potential risks to human health and the environment resulted in the 1972 amendments to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). The amendments required that all existing pesticides be reregistered using current health and environmental standards. Registration requirements now represent a significant cost to the manufacturer. In 1992 and 1993, only 31 new active ingredients were duly registered as pesticides under FIFRA.

Pesticides have been found in surface water and ground water samples, sometimes at levels that exceed health standards or at levels harmful to wildlife. In most studies, however, pesticides are detected in only a small portion of the samples, and usually at very low levels. Exceptions are the more soluble and persistent pesticides, such as atrazine, which are commonly found in streams draining agricultural areas during or just after storm events following application.

Even when the label instructions are carefully adhered to, a small portion of pesticides applied (from nearly zero to over 5 percent) can reach surface and ground water (Baker et al. 1992). For example, a loss of 1 percent of a one-pound per acre pesticide application can contaminate all the drainage from a midwestern field in a normal year at 5 parts per billion. While this amount may seem small, it can cause concern, especially if the drainage water enters drinking water supplies.

Even within agriculture, other mechanisms than leaching and runoff from farm fields are important sources of contamination. Indeed, the majority of the pesticides found in ground water originate from quasi-point sources, such as applicator loading and mixing sites, and improper disposal, storage, and handling of chemicals on the farm. Accidental spills can contaminate both surface and ground water.

Monitoring and analysis can sometimes measure pesticide concentration in water but cannot identify the source—agricultural or nonagricultural, point, nonpoint, or quasi-point—of the pesticide. Monitoring results indicate the existence of a water quality problem with pesticide use. However, more information is needed on the relative importance of the various sources of contamination before effective policies can be developed to reduce the potential for agricultural pesticide contamination of water.

The persistence of a pesticide in the environment and three physical properties of pesticides—soil sorption propensity, vapor pressure, and solubility—determine the tendency of pesticides to move from the application site.

Pesticide persistence

Persistence is a pesticide's resistance to decomposition through chemical, photochemical (sunlight), and microbial action. It is expressed in terms of half-life, or the time it takes for 50 percent of the pesticide to break down. Pesticides that persist are more likely to move off-site than less persistent ones. Most of the time pesticides decompose into less toxic chemical forms, but sometimes the metabolites retain pesticidal properties. DDT is an example of a pesticide with high persistence (a half life of several years). Atrazine with a half life of 60 days is one of the more persistent pesticides in widespread use, which explains why it is found more frequently than other chemicals in surface and ground water.

Sorption is the binding of the chemical to the soil. Some pesticides bind more strongly than others. Pesticides that are strongly adsorbed tend not to leach, but are lost with the soil through soil erosion processes. Pesticides that are weakly adsorbed are lost mainly in surface runoff and percolation.

Vapor pressure is the measure of a pesticide's tendency to evaporate. Losses in excess of 50 percent have been measured when pesticides were applied on windy days. Wind speed, air temperature, soil temperature, humidity, and equipment operation determine the amount of losses to the atmosphere. Evaporation can continue long after application. Losses are less for pesticides with a low vapor pressure. In an Iowa State University study, for example, about 5 percent of the herbicide propachlor evaporated in the first 24 hours after application. Less than 1 percent of the applied cyanazine evaporated, largely because its vapor pressure is 140,000 times less than propachlor's.

Setting Health Hazards for Pesticides

Baker (1993) demonstrated EPA's procedures for setting health hazards for pesticides with a simplified atrazine example.

- The atrazine lifetime health advisory level (HAL) for humans was derived from laboratory animal studies, which determined the lowest observed adverse effect level (LOAEL) at which any effect of ingesting atrazine could be detected.
- The next level below the LOAEL, at which no effect was observed, is the no observed adverse effect level (NOAEL).
- The lifetime HAL is the NOAEL daily rate divided by a large safety factor (1,000 for atrazine) and converted to a drinking water concentration for a person of specified size who drinks water for a specified length of time. For an exposure duration of 70 years, the HAL for atrazine is 3 ppb.
- The EPA may also establish a maximum contaminant level (MCL) for the substance in question, based on an assumed lifetime exposure. For atrazine, the MCL corresponds to 1/5000 of the NOAEL dose for the most sensitive animal species tested (Richards et al. 1994).

Water solubility determines the amount of pesticide that is likely to be removed by runoff or by leaching below the root zone with excess water. Although the relation between soil sorptivity and water solubility is complex, it is generally true that given a particular soil adsorption level, the greater the water solubility, the more potential there is for losses from the field when it rains or when the field is irrigated.

Soil properties that affect pesticides

Soil characteristics also affect the potential for pesticides to stay in or move from the field. The three major characteristics are texture, permeability, and organic matter.

Soil texture is an indication of the relative proportions of sand, silt, and clay in the soil. Pesticides tend to be adsorbed on clay and organic matter. The higher the clay content, the greater the number of binding sites for pesticide retention. Clay content is particularly important in the subsoil, where the organic matter content is generally much lower than in the surface soil. Coarse, sandy soils generally allow water to move rapidly downward and offer few opportunities for adsorption. Finer textured soils generally allow water to move at much slower rates, and they contain more silt and organic matter to which pesticides and other chemicals may be adsorbed.

Soil permeability is a general measure of how fast water can move downward in a particular soil. Permeability is controlled by soil structure, which is the way individual soil particles clump together to form larger aggregates. These aggregates have internal pore space, and form additional pore space between aggregates. This pore space is key to water retention and movement through the soil. Well-structured soils have a good distribution of pore space size. Poorly structured soils (compacted or sandy) have a narrow distribution of pore space size.

Coarse-textured sandy and gravelly soils have the largest pores and the most rapid permeabilities, but lack structure. Fine-textured clayey soils have very tiny pores, very slow permeabilities, and excessive structure. Medium-textured loams, silt loams, and clay loams have moderate structure and intermediate rates of soil permeability. The more permeable soils must be carefully managed to prevent chemicals from reaching ground water, whereas slowly permeable soils must be managed to control runoff.

Organic matter content is the most important variable affecting sorption of pesticides onto soil particles. Adsorption retains chemicals in the soil, thus allowing more time for degradation by chemical and biological processes. Organic matter provides binding sites and is very reactive chemically. Soil organic matter also influences how much water the soil can hold before movement occurs. Increasing organic matter will increase the water-holding capacity of the soil. Farming practices that return crop residues and animal wastes to soils help maintain soil organic matter content. Practices that harvest or destroy residues tend to reduce soil organic matter, leading to greater pesticide losses from the field.

Pesticide losses in field runoff and leachate

Wind or water is required to transport pesticides from the field to surface or ground water. Whether and how much a pesticide migrates from the field where it was applied, depends on the complex interaction of pesticide properties with soil characteristics and weather conditions. For example, the half-life of a chemical is not a constant value, but can vary considerably depending on soil temperature and moisture, microbial populations, organic material, the pH of the soil, and soil type. Many of the factors that determine pesticide losses from a field are influenced by management practices and can be partly controlled by the farmer.

Not all surface water bodies are equally vulnerable to pesticide contamination. The highest risk situations (Kerle et al. 1994) involve a combination of two or more of the following conditions:

- the field is located directly upslope and adjacent to a pond or stream,
- pesticides are applied to foliage or soil surface immediately before heavy rainfall or irrigation that induces runoff or erosion,
- soils have a high erosion or runoff potential, and/or
- pesticides are applied to frozen ground.

Rainfall affects pesticides by (1) breaking their bond with the soil and dissolving them in water, leading to runoff or leaching, or (2) loosening and transporting pesticide-laden soil particles through erosion. The greatest losses of pesticides from the field occur in the first runoff event after application. Losses in surface runoff are the greatest—up to 5 percent of the amount applied. Losses to subsurface drainage and percolation, however, are far less—typically less than 0.5 percent. The amount lost depends entirely on the timing and intensity of rainfall. Rainfall interacts with chemicals in a shallow depth of soil, in the one-fourth to one-half inch called the mixing zone. The pesticide concentration in initial runoff water decreases the longer it takes runoff to begin during a rainstorm. Leaching of the pesticide from the mixing zone during a rainstorm decreases concentrations, both in the initial runoff and during the runoff event (Baker et al. 1992).

The amount of rain that infiltrates before runoff begins is essential in determining pesticide losses. For example, compaction, which causes more runoff to occur sooner, increases both concentrations and losses. The presence and the nature of macropores can also have a significant influence on initial infiltration. For example, if pesticides are applied on the surface and an intense storm produces saturated soil or ponding, chemical leaching through the macropores would increase. On the other hand, if the rainfall is gentle and soaks in before ponding, pesticide-laden water within aggregates would generally be bypassed by water flowing in the macropores, decreasing the leaching potential (Baker et al. 1992).

Other site conditions affect pesticide runoff and leaching. A shallow depth to ground water offers less opportunities for pesticide sorption and degradation. The travel time of the pesticide to the water table may range from days to weeks if the depth to the water table is shallow, the soil is permeable, and the amount of rainfall exceeds the water-holding capacity of the soil. The travel time may be on the order of decades if these conditions do not hold and more opportunity is provided for degradation.

The presence of impermeable layers in the soil profile and underlying strata may limit the vertical movement of pesticides. These same impermeable layers, however, may also contribute to the lateral flow of shallow ground water and to the eventual discharge of ground water and its contaminants to surface water.

Consequently, the potential for water contamination by pesticide losses from field runoff or from leaching varies from region to region, from county to county, and even, to some extent, from field to field. Best management practices for pesticide use are highly specific to crops and locations.

Management to reduce pesticide pollution

In the last 10 to 15 years, regulatory actions, new pesticide chemistry, improved and new pesticide management practices, and a better understanding of pesticide risks have brought us closer to our goal of maintaining agricultural productivity while protecting human health and the environment.

Key management practices that can be used to reduce pesticide pollution are

- improving timing and application methods to minimize pesticide losses;
- selecting the pesticides and pesticide formulas that are most suitable to the targeted species and least toxic to nontargeted species;
- minimizing application rates to control target pests;
- adding nonchemical pest control measures, such as crop rotations and winter cover crops;
- practicing soil management and crop residue management to reduce runoff or percolation;
- implementing erosion and runoff control measures to reduce losses through runoff and leaching; and
- using Integrated Pest Management, which embodies most of the previous recommendations.

Research shows that careful timing of application is perhaps the single most important management decision affecting pesticide loss. Applications prior to storms and windy days result in substantial losses. Choosing optimal application times is not easy, however, because weather is unpredictable and the time frame short within which applications need to be made to maintain rapid growth of the plant.

For example, in the Wye River watershed in Maryland, dissolved concentrations of simazine, atrazine, cyanazine, and metolachlor were measured in surface runoff during 1984 to 1986. In 1984, 4 percent of the applied herbicides were logged in the runoff following several high intensity storms. In each of the following two years, however, less than 0.4 percent of the herbicide applied was logged in runoff (Brinsfield et al. 1987).

Soil incorporation can significantly reduce surface and atmospheric losses of pesticides by decreasing the amount of pesticides in the shallow surface, or mixing zone. The practice minimizes pesticide exposure to wind and rain.

The selection of pesticides and pesticide formulations can also have profound effects. Choosing pesticides that are less persistent, more strongly adsorbed, and of lower volatility minimizes losses from the field, while selecting postemergence herbicides can reduce overall losses because they have little or no soil residual activity and are applied only as needed. Use of granular formulations, where feasible, can also dramatically reduce losses. Research has shown that starch-encapsulated atrazine applications can reduce the amount of atrazine moving through 12 inches of soil by 60 to 80 percent compared with commercial formulations (Hickman et al. 1995). Volatilization losses were also much less for the starch-encapsulated formulation (Perencevich et al. 1995). When choices are available, selecting the less toxic pesticide helps reduce risk to humans and wildlife.

Reducing the rate of application directly reduces the amount of pesticide leaving a field. Banding, which reduces the area of application, effectively reduces the application rate for the field. Determining the pest threshold before resorting to chemical control can keep the number of applications to a minimum as well as reduce the acres treated within a field.

Crop rotation tends to reduce the need for pesticides, sometimes eliminating the need for their use. For example, corn following soybeans usually does not require rootworm insecticides. Research indicates that only 8 percent of the acreage in corn/soybean rotation was treated with insecticide, compared to 61 percent and 48 percent for the 3-year and the 2-year continuous corn sequence (Lin et al. 1995). Rotating crops to control insects has a long history and was one of the most important methods of insect control before insecticides came into widespread use. Crop rotations can also be effective against disease; plant pathogens often have narrow host ranges and will not survive in the absence of the host. Crop rotations are known to reduce many diseases in wheat and tobacco production.

The way soil is tilled plays a significant role in potential pesticide loss. For example, an Iowa State University study found that ridge tillage reduced runoff 35 percent, erosion 62 percent, and alachlor loss 25 percent.

Crop residue management can sometimes decrease pesticide loss by increasing organic matter and providing more binding sites for the sorption of chemicals. Increased organic matter aids in the decomposition of pesticides. The water-holding capacity of residue leads to substantial reductions in surface runoff. More crop residue, however, also increases the possibility of spray interception and subsequent pesticide wash-off or volatilization. If wash-off becomes part of surface runoff rather than soaking into the soil, pesticide concentrations may actually be higher in conservation tillage than where pesticides are directly applied to the soil.

Strip cropping, contour buffer strips, grassed waterways, and mixed vegetative buffer strips can slow runoff and trap sediment with sorbed pesticides by interrupting the flow of water from a field.

New products and techniques, such as a herbicide-tolerant cotton; corn and tobacco strains that produce their own insecticide; ultralow volume applications of herbicide in paraffin oil (Hanks, 1995); and weed-sensor spray systems, will help reduce the occurrence of pesticide residues in water in future years. Farmers are adopting newly developed practices of integrated pest management (IPM). With IPM, for example, farmers determine the need for treatment and select the herbicide after the weed problem has been identified. However, with these postemergent treatment programs greater attention must be paid to management details, such as close monitoring of the weather and weed development.

Farmers and ranchers are responding to the challenge of sustaining productivity while protecting water quality. IPM and conservation tillage practices are increasing, and substantial progress has been made in reducing soil loss from fields which in turn reduces sorbed pesticide loss. One reason for the progress is that as the solutions generally reduce inputs, they also reduce costs. However, the new technologies are also more management intensive, requiring farmers to invest more time and effort in management inputs. For example, to use IPM in its highest form, the practitioner needs to understand pest and crop biology, consider root causes of pest population explosions, and know how other management factors influence pest populations and the beneficial organisms that could potentially hold some pests in check.

USDA is providing a critical role in the adoption of IPM through programs of technical assistance, education, information, and financial assistance.

Salinity

The salt content (salinity) of soils is associated with inadequate drainage. It is pervasive in western arid and semiarid areas because precipitation can be insufficient to induce adequate leaching and because pothole areas and closed basins are common (Walker, 1995).

All irrigators must deal with salinity since all water tapped for irrigation contains salts. Much of that water is taken up by plants and returned to the atmosphere but only pure water evaporates from the soil surface or transpires from plant surfaces. Salts are left behind in the soil (Natl. Res. Counc., 1993). Either through precipitation or irrigation management, these salts must be leached from the soil since excess salinity negatively affects vegetative growth and can reduce crop yields. Chemical degradation from salinization and toxic elements can lead to rapid decline in soil and water quality. At high levels, salts can be toxic and reduce water uses.

About 14 million irrigated acres are affected by salts. An estimated 2.5 million acres of agricultural dryland has also been salinized through saline seeps. Salinity problems also occur in humid regions through sea water intrusion into coastal areas.

Regional problems

About 25 percent of irrigated cropland in the United States (14 million acres) is significantly affected by salts in soil and water (Hedlund and Crow, 1994). Crop yields decrease as levels of salinity increase. For example, field beans yield only 40 percent of their potential, even at a low soil salinity level. Conditions in four major regions illustrate water quality problems arising from salt and toxic trace elements.

San Joaquin Valley, California

In 1987, California had an annual agricultural production of over $14 billion. Some 4 million acres—nearly 50 percent of the State's irrigated cropland—were threatened by salinity, toxic trace elements, high water tables, and return-flow disposal problems.

Some 850,000 acres of the San Joaquin Valley's 2.5 million irrigated acres are affected by inadequate drainage and accumulating salts. Inadequate drainage has long been a serious problem. The 1983 discovery of deformities and deaths among aquatic birds at Kesterson Reservoir—later linked to high levels of selenium in irrigation drainage water—led to the formation of the San Joaquin Drainage Program in 1984. This program focuses on reducing and controlling drainage water and on containing and isolating toxicants such as selenium. The valley's drainage and salinity problems result from three separate but related conditions—shallow ground water, salinity, and potentially toxic trace elements.

Shallow ground water. After vast amounts of surface water were imported for irrigation, shallow ground water pumping reductions caused levels to rise to within 5 feet of the surface, worsening drainage on an additional 313,000 acres. Previously, only 537,000 acres had reported poor drainage.

Salinity. Irrigation-induced leaching of the soil and accumulated salts—both from leaching and from imported water—have concentrated dissolved salts in shallow ground water. Although the imported water is generally of good quality, with an average salinity less than 350 parts per million (ppm), the large volume of imported water brings with it about 1.6 million tons of salts annually. The arid soils of the western San Joaquin Valley contain substantial amounts of naturally occurring salts that contribute heavily to the soil solution and subsurface drainage water. About half the soluble salts in the crop root zone come from the soil. Evapotranspiration increases the concentration of salts.

Trace elements. Toxic and potentially toxic trace elements occur naturally in some soils and are leached into shallow ground water during irrigation. Selenium, boron, molybdenum, and arsenic are the primary concern. Selenium is of greatest concern because of its wide distribution and toxicity. Selenium concentrations in shallow ground water range from less than one to 3,800 parts per billion (ppb), with a median concentration of 6 ppb. In spring 1984, water entering Kesterson Reservoir had an average selenium content of 385 ppb. To protect freshwater aquatic life, EPA has established ambient water quality criteria for selenium of 5 ppb for chronic toxicity and 20 ppb for acute toxicity.

The San Joaquin Drainage Program identified a broad range of management options to solve subsurface drainage and salinity problems, including

- improving existing irrigation practices or adopting new irrigation methods;
- improving irrigation scheduling and management of irrigation systems;
- managing the shallow water table to increase its contribution to evapotranspiration; and
- reusing irrigation drainage water on salt-tolerant crops.

Producers are individually adopting these practices to gain short-term benefits, but none of the practices will solve the San Joaquin salt problem in the long run. Some of them, such as reusing irrigation drainage water, will eventually make the problem worse (Walker, 1995).

Imperial Valley, California

Irrigation drainage water from farm fields in the Imperial Valley enters the Salton Sea. Without irrigation, the sea would be dry. Drainage installed in irrigation districts is apparently controlling salinity in the croplands. Since the sea has no outlet, evaporation concentrates salinity and toxic elements as do increases in irrigation efficiency. Continued irrigation will reduce the water's value for fish and wildlife. Society must decide whether to continue to irrigate and pollute the Salton Sea, or to stop irrigation and dry up the sea—thus losing $4 to $5 billion in agricultural crop production.

Colorado River Basin

The Colorado River Salinity Control Program provides USDA assistance to seven States to identify salt source areas, install conservation practices to reduce salinity loads in the river, and carry out research, education, and monitoring (U.S. Dep. Agric. 1994a). Salinity is an important issue for producers in both the United States and Mexico. The primary source of salts in water and soils is the chemical weathering of earthen materials (i.e., minerals) that are constituents of rocks and soils. Irrigation contributes salt in two ways: (a) salt is concentrated in return flows or left on the soil surface after irrigation water has evaporated; and (b) it dissolves from excess irrigation water leaching through ancient salt deposits and saline aquifers.

Although these seven states are acting to reduce salinity damages, the Colorado River continues to cause critical salinity problems for Mexico. Mexico is allowed by treaty to claim about 7 percent of the river's flow. Salt concentration is typically 50 ppm near the Colorado's headwaters, but it has in the past reached much higher levels—as high as 1,100 ppm—before entering Mexico. However, such high concentration levels are unlikely in the future. The completion of the filling of Lake Powell, repurchase and retirement of irrigated lands by the Bureau of Reclamation in Wyoming and Arizona, and producer adoption of improved canal linings and more efficient irrigation practices and scheduling are among measures that, since 1987, have reduced annual salt load to the river by 164,000 tons.

Arkansas River Basin

The total dissolved solids concentration of irrigation water is at least 2,000 ppm in southeastern Colorado and frequently reaches 4,000 ppm in the lower reaches of the valley. Salinity in the Basin is mostly a problem of the reuse of limited water—some 85 percent of the total surface supply is consumed before the river leaves Colorado. Public agencies, especially the U.S. Army Corps of Engineers, have acted to intercept the salt springs that diminish water quality in the middle and lower reaches of the Arkansas.

Saline seeps and salt water intrusion

Saline soils are not limited to irrigated areas. Mineral weathering and dissolution of cretaceous shale occurs over a large portion of the arid West. Saline seeps occur when water that exceeds plant requirements percolates unchecked below the root zone, then moves laterally downhill and emerges in a seep area. These seeps frequently occur where farmers practice wheat fallow rotations. Seeps have affected about 500,000 acres of cropland in the Great Plains from Montana to Texas and some 2.5 million acres for all land uses.

The Triangle Conservation District Saline Seep project in Montana is one solution to this local problem. Local farmers are changing their land use and management over the water recharge area by switching to a flexible cropping system. The new system ensures that crops grown in sequence will use all available soil water, regardless of vagaries in the weather.

The Saline Seep Program in the Central Rolling Red Plains area (Texas) focuses on "salt" spots that hamper crop production in cultivated fields. Subsurface drains and deep-rooted vegetation that uses large amounts of available soil moisture are proven methods to reduce accumulations of salty water in shallow water tables.

Seawater can intrude where coastal aquifers and freshwater are near the open ocean. Well water can be salinized if formation water is not flushed out, if seawater intrudes, or if pumping induces landward flow. The chemical composition of seawater changes as it intrudes into a freshwater aquifer. In the coastal and island areas of 21 States, salt water intrusion is jeopardizing municipal freshwater supplies and entering the water table in coastal farmlands.

Changes in agricultural resource management

Land and water management in the agricultural industry directly affects the movement of pollutants to surface and ground water. From 1982 through 1992, changes occurred in land use and soil erosion, irrigated cropland, use of nitrogen and phosphorus from commercial fertilizer and animal manures, and pesticide use.

Land use

Changes in the amount, intensity, and geographical distribution of agricultural land and water use can have a significant effect on water quality because food, feed, and fiber production uses agrichemicals and may boost erosion rates and sediment yield.

Table 2-3 shows that cropland used for crops decreased each year from 1982 to 1987 and jumped in 1989, but as of 1992 remained below the 1982 level.

Table 2-3 Major uses of U.S. cropland, selected years 1982 to 1992

U.S. Cropland[1]	1982 (millions of acres)	1987 (millions of acres)	1992 (millions of acres)
Cropland—used for crops	383	331	337
Cropland—harvested[2]	347	293	305
Crop failure	5	6	8
Cultivated—summer fallow	31	32	24
Cropland idled by—			
all federal programs	11	76	55
Annual	11	60	20
Long-term	0	16	35
Total[3]	394	407	392

Sources: U.S. Department of Agriculture (1994d) and (1996).

1 Conterminous United States only; fewer than 200,000 acres were used for crops in Alaska and Hawaii

2 Includes double-cropped acreage

3 Does not include cropland used as pasture or idle land not in Federal programs that is normally included in the cropland base.

The 1982 to 1987 decrease in cropland harvested– some 60 million acres—reflects an increase of 67 million acres in idled cropland. Planted and harvested acreage followed the same pattern. Growth in the annual set-aside acreage under USDA commodity programs and in the 10-year CRP accounted for the expansion in idled acreage.

The inverse relationship between harvested and idled cropland generally continued through 1992. From 1987 to 1992, harvested cropland expanded slightly (12 million acres) while 21 million acres of idled land returned to production. The driving force in idling land was the long-term CRP. In these five years, producer enrollments in the CRP expanded by some 10 million acres.

Wheat and corn acreage are, by far, the largest to be idled. From 1.6 million acres idled in 1982, wheat idled rose to 29.6 million acres in 1988, and was still an estimated 17.9 million acres in 1992. Corn showed the same pattern, rising from 2.1 million acres in 1982 to 23.3 million acres in 1988 and falling back to 9.3 million in 1992 (U.S. Dep. Agric. 1993).

Irrigated land

Chemical use is generally more intense per acre on irrigated than on nonirrigated cropland. Nationally, irrigated land decreased from 1982 to 1987 and expanded from 1987 to 1992—a pattern similar to that of harvested cropland (table 2-4). Over the 10-year period, however, cropland use intensified as irrigated acreage rose from 12.8 to 15.4 percent on land used for crops.

The three regions with the most irrigated acreage—Mountain, Pacific, and Northern Plains—remained about the same over the decade. However, regions experiencing the greatest rate of intensification of cropland use through irrigation were the Delta (74.2 percent) and the combined Lake States Corn Belt regions (64.7 percent).

These changes in agricultural land and water use are mirrored in the following nutrient and pesticide discussions.

Table 2-4 Irrigated land in farms, by Farm Production Region, selected years 1982 to 1992

Region	1982[1] (millions of acres)	1987[1] (millions of acres)	1992[2] (millions of acres)
Northeast, Appalachia and Southeast	2.7	3.0	3.4
Lake States and Corn Belt	1.7	2.0	2.8
Northern Plains	9.3	8.7	10.7
Delta States	3.1	3.7	5.4
Southern Plains	6.1	4.7	5.4
Mountain	14.1	13.3	14.3
Pacific	11.9	10.8	10.7
United States[3]	49.0	46.4	52.8

Source: U.S. Department of Agriculture (1993).
1 Census of Agriculture.
2 Preliminary estimates.
3 Includes Alaska and Hawaii. Totals may not tally exactly, due to rounding.

Soil erosion

Major types of soil erosion by water are sheet and rill erosion, classic (large) gully and ephemeral (temporary) gully erosion, and streambank erosion. Wind erosion is also a major type of erosion.

In 1992, most sheet and rill erosion was in the eastern United States where precipitation is heaviest (fig. 2-6). West of the 100th meridian, the only significant amounts of erosion from a national perspective are in the Palouse region of Washington, Oregon, and Idaho; the Snake River Valley in eastern Idaho; and the eastern Colorado Plains. Wind erosion occurs primarily in the western United States (fig. 2-7). From a national perspective, specific areas of wind erosion are western Minnesota, Texas, Oklahoma, New Mexico, eastern Colorado, and eastern Montana.

In 1982, total cropland erosion on private, nonfederal lands was about 3.1 billion tons of which 1.7 billion tons was sheet and rill erosion and 1.4 billion tons was wind erosion (fig. 2-8). By 1992, the total had fallen one third to 2.1 billion tons. Sheet and rill as well as wind erosion had fallen significantly—to 1.2 billion tons and 0.9 billion tons, respectively.

Implementation of the CRP (fig 2-9) and the conservation compliance provisions of the 1985 Farm Bill were important to the achievement of this progress. Note that the source of these data, the 1992 NRI, was conducted two years before the conservation compliance provision required producers to have fully implemented, approved soil conservation plans on highly erodible land (HEL).

The conservation compliance provision requires producers with highly erodible land to have an approved conservation plan fully implemented by January 1, 1995, to maintain eligibility for USDA program benefits. The United States has an estimated 150 million acres affected by the HEL provisions. As of December 31, 1993, some 1.2 million producers had developed conservation plans on 143.5 million HEL acres. Nearly 80 percent of the plans have been fully implemented (U.S. Dep. Agric. 1994c). NRCS CTA evaluations determined that erosion on the most highly erodible lands was reduced to 6 tons per acre per year in 1995.

The average annual rate of sheet and rill erosion on cropland dropped from 4.1 tons per acre in 1982 to 3.1 tons per acre in 1992. Wind erosion rates fell from 3.3 tons per acre to 2.5 tons per acre. However, land

Conservation Reserve Program

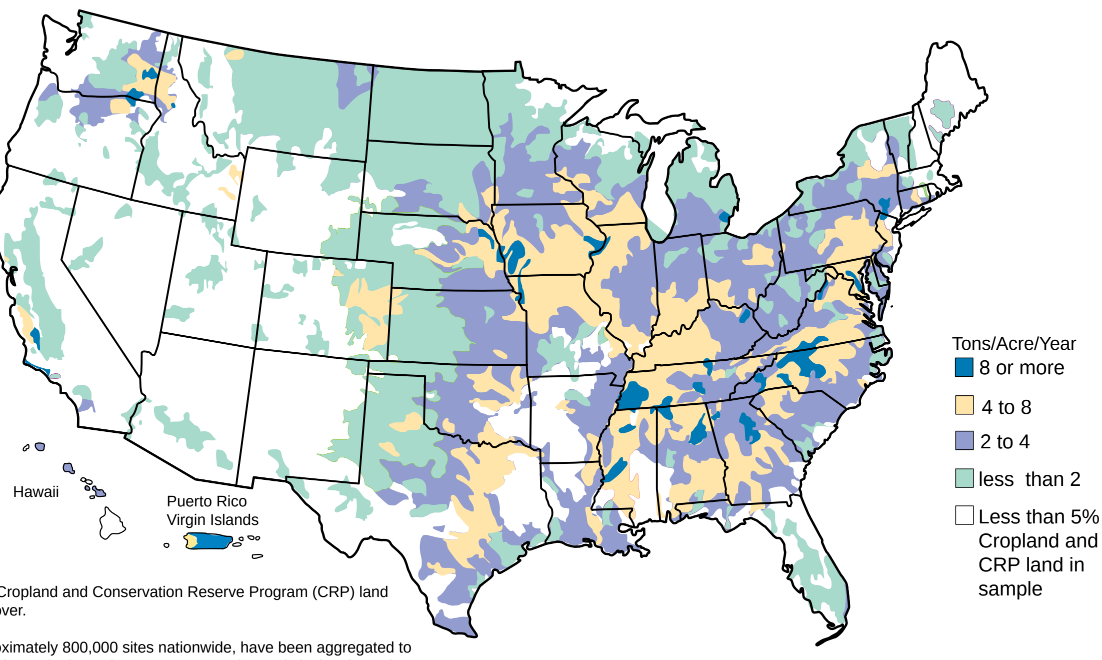
The Conservation Reserve Program – a key program – as well as the conservation compliance provision of the 1985 Food Security Act dramatically reduced erosion rates during the 1982 to 1992 period and, ultimately, sediment reaching waterbodies.

Established in the 1985 Farm Bill, CRP permits landowners to retire highly erodible or environmentally sensitive cropland from crop production for 10 to 15 years. In 1990, the CRP was modified to target enrollments to water quality. The CRP has two main objectives:

- to reduce surplus agricultural commodity supplies that lower food and grain prices and raise Federal farm program costs, and
- to enhance environmental benefits with emphasis on improved water quality.

Since 1985, 36.4 million acres – about 8 percent of all U.S. cropland – have been enrolled at an average rental rate of $50 per acre. Some 26 million acres are designated as highly erodible land (HEL). The average erosion rate on CRP-enrolled lands has declined from 20.6 to 1.6 tons of soil per acre per year for a total estimated reduction in erosion of 694 million tons per year (U.S. Dep. Agric. 1994b).

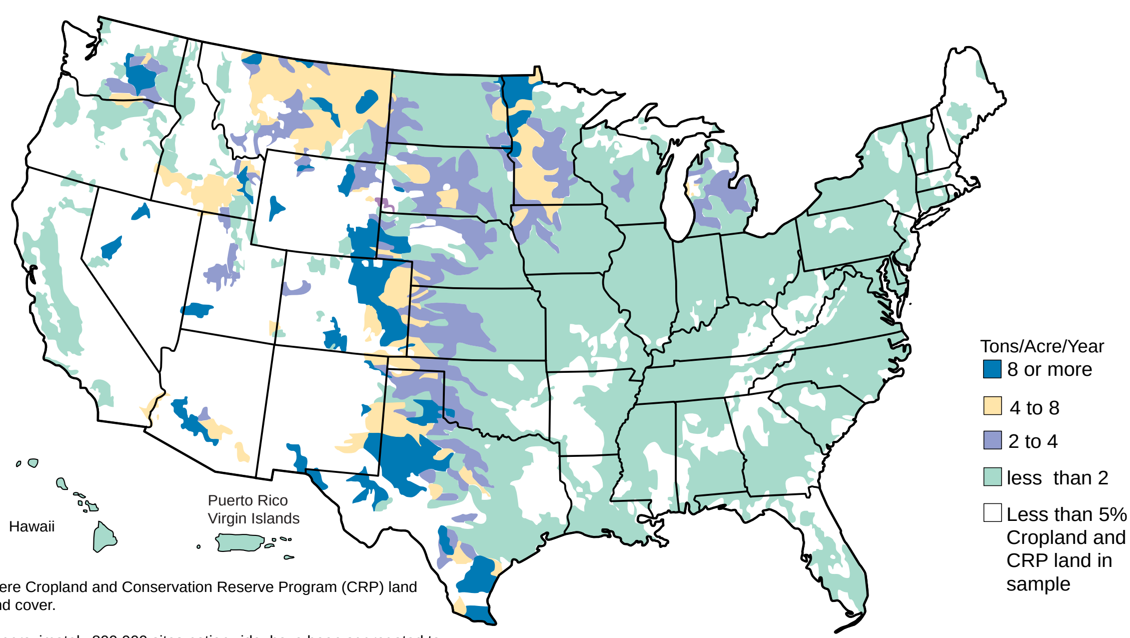
Figure 2-6 Average annual soil erosion by water on cropland and Conservation Reserve Program land, 1992



Note: Data are only present where Cropland and Conservation Reserve Program (CRP) land are 5 percent or more of the land cover.

NRI sample data, collected at approximately 800,000 sites nationwide, have been aggregated to create estimates for USGS hydrologic cataloging unit areas. Because the statistical variance in some of these areas may be large, the map reader should use this map only to identify broad spatial trends and avoid making highly localized interpretations.

Figure 2-7 Average annual soil erosion by wind on cropland and Conservation Reserve Program land, 1992



Note: Data are only present where Cropland and Conservation Reserve Program (CRP) land are 5 percent or more of the land cover.

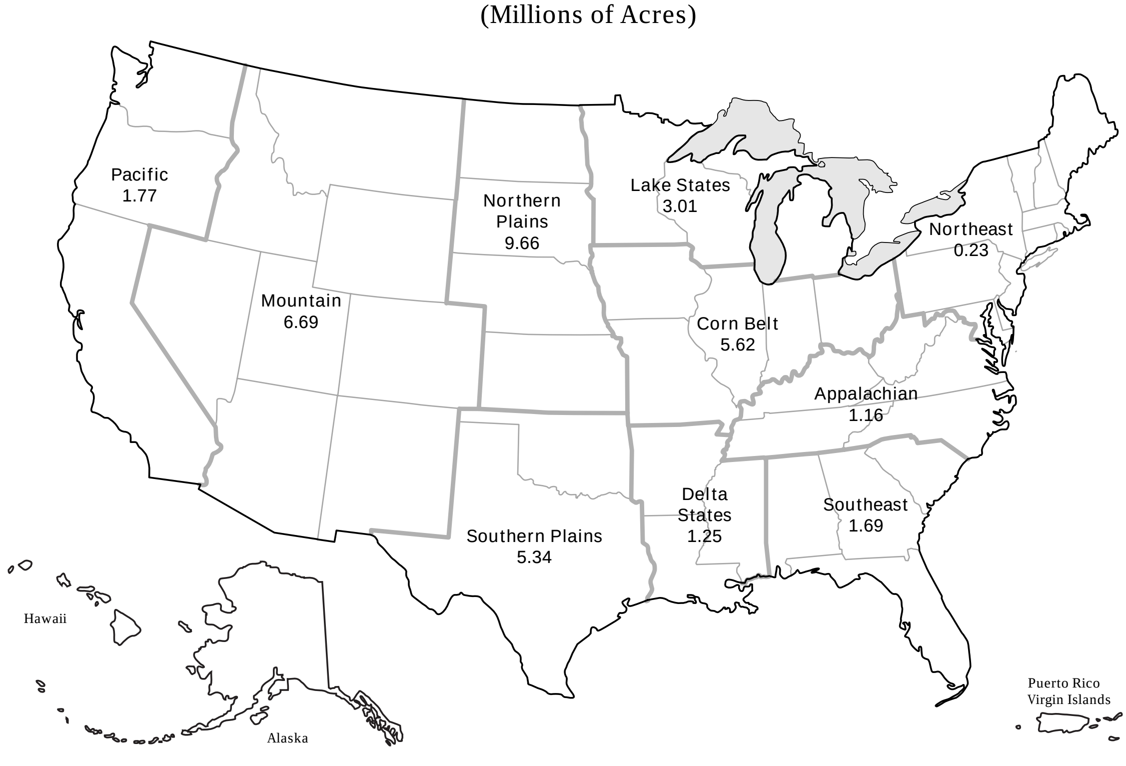
NRI sample data, collected at approximately 800,000 sites nationwide, have been aggregated to create estimates for USGS hydrologic cataloging unit areas. Because the statistical variance in some of these areas may be large, the map reader should use this map only to identify broad spatial trends and avoid making highly localized interpretations.

Figure 2-8 Total wind erosion and sheet and rill erosion on cropland, 1982 to 1992

Source: USDA Natural Resources Conservation Service, 1992 National Resources Inventory

Figure 2-9 Acreage enrolled in Conservation Reserve Program, as of the 12th signup (1993), by farm Production Region (Lander, 1994a)

(Millions of Acres)



U.S. Total: 36.39 million acres

Data Source: Material prepared by C. Lander for RCA Nutrients Report, draft 7/21/94.

Notes:
- Numbers are in millions of acres.
- Areas outside conterminous U.S. have less than 50,000 acres.

enrolled in the CRP was not included in these cropland erosion calculations, even though it was part of the cropland base in 1982. Since CRP land is protected from erosion by grass or tree cover, it is reasonable to assume that including CRP in the 1992 calculations would further lower the average annual erosion rates.

Figure 2-10 shows the distribution of progress in reducing combined sheet and rill and wind erosion rates on cropland and CRP acres. Key areas showing significant reductions include the High Plains of Texas, Oklahoma, and New Mexico; the northern Great Plains; the Corn Belt; and large areas of the Southeast. Nationally, the most important area of increased erosion is in western Colorado.

Nitrogen and Phosphorus

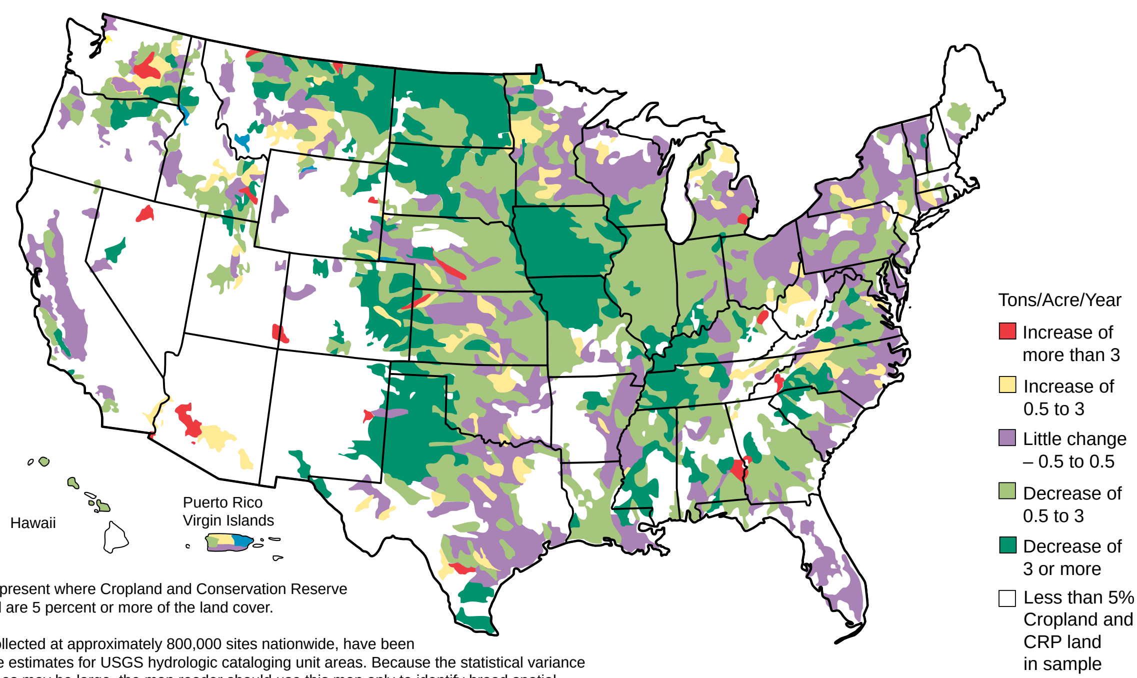
Nationally, the number of fertilized cropland acres showed an insignificant change over the decade—a 7.2 percent contraction during 1982 through 1987 offset by a 7.3 percent increase during 1987 through 1992 (table 2-5). The regions that experienced the highest acreage increases over the 10-year period were the Northern and Southern Plains. Most of the other regions showed acreage decreases.

Grazing land is fertilized less heavily than cropland. Over the decade, fertilized grazing land acreage increased 20.1 percent. Most fertilized grazing land is located in the Southern Plains and Southeast regions.

Commercial fertilizers

In agricultural production systems, commercial synthetic fertilizers account for most of the nutrients used. Total consumption of commercial nitrogen fertilizer for all farm and nonfarm uses during 1982 through 1987 decreased from about 11 million to 10.2 million tons (fig. 2-11). A very sharp drop in nitrogen fertilizer consumption occurred in 1983. It is attributed to the USDA Payment-in-Kind (PIK) Program, which diverted an estimated 75.7 million acres from corn, sorghum, oats, wheat, barley, rice, and upland cotton production. Enrollment of land in the CRP had a downward effect on fertilizer use in these years. Figure 2-11 shows a definite upward trend during 1987 through 1992—a time when acres harvested also rose. During this time nitrogen consumption rose from about 10.2 million to 11.4 million tons, an increase of nearly 12 percent.

Figure 2-10 Change in average annual soil erosion by wind and water on cropland and Conservation Reserve Program land, 1982 to 1992



Note: Data are only present where Cropland and Conservation Reserve Program (CRP) land are 5 percent or more of the land cover.

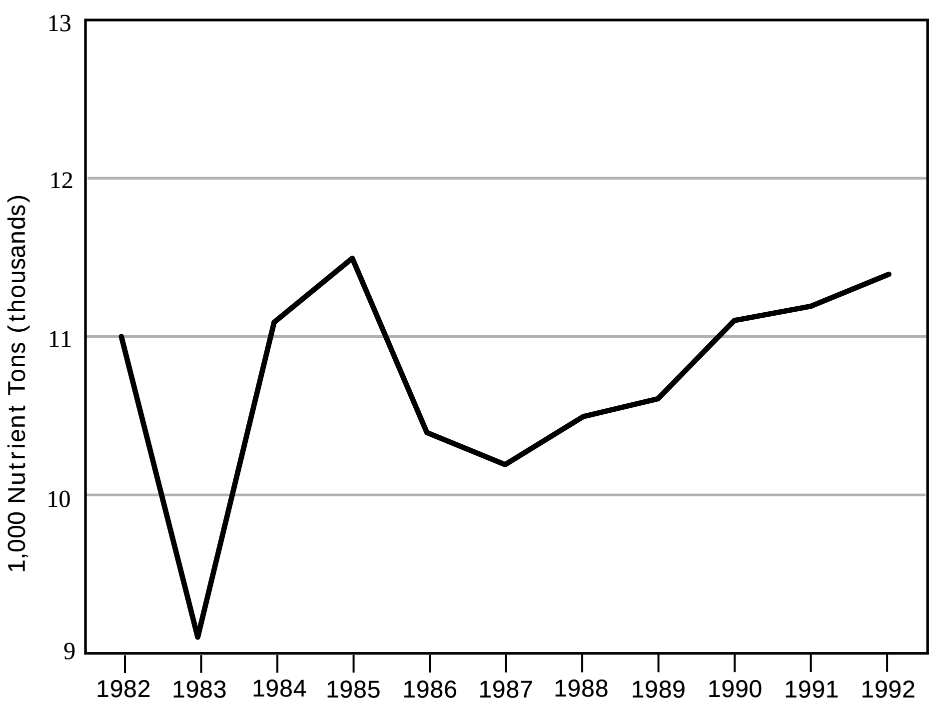
NRI sample data, collected at approximately 800,000 sites nationwide, have been aggregated to create estimates for USGS hydrologic cataloging unit areas. Because the statistical variance in some of these areas may be large, the map reader should use this map only to identify broad spatial trends and avoid making highly localized interpretations.

Table 2-5 Cropland and grazing land fertilized, by Farm Production Region, selected years, 1982 to 1992

	Cropland			Grazing land		
	1982 (millions of acres)	1987 (millions of acres)	1992 (millions of acres)	1982 (millions of acres)	1987 (millions of acres)	1992 (millions of acres)
Northeast	8.5	7.7	7.5	0.3	0.3	0.3
Appalachian	12.2	10.4	11.0	1.8	2.2	2.5
Southeast	10.5	7.6	8.0	2.5	2.5	2.
Lake States	25.3	23.6	24.6	0.2	0.3	0.2
Corn Belt	54.0	49.8	53.2	2.4	2.9	3.3
Delta States	10.9	8.9	10.2	1.4	1.4	1.6
Northern Plains	42.0	43.6	47.7	1.1	1.1	1.2
Southern Plains	18.4	16.4	19.4	3.7	4.3	4.8
Mountain	14.4	14.7	14.9	0.4	0.4	0.4
Pacific	13.9	12.2	12.7	0.4	0.4	0.3
Other	0.3	0.3	0.2	*	*	*
United States	210.3	195.1	209.5	14.5	15.9	17.2

Source: C. Lander, 1994a. Figures from U.S. Census of Agriculture not available as of 8/10/94.
*= less than 50,000 acres

Figure 2-11 Nitrogen consumption, all applications, 1982 to 1992 (C. Lander, 1994a)



The commercial phosphate consumption pattern differed markedly from that of nitrogen. Except for an increase in 1984 and 1985, the pattern remained nearly unchanged through 1992 (fig. 2-12). Because consumption was relatively high in 1982, use during the period was about one-fifth below that of 1982 (except for 1984 and 1985).

Figures on nitrogen and phosphate use are more significant on the regional than on the national level. Dramatic differences occurred among the regions during this decade (table 2-6). Among the top four regions for nitrogen consumption (i.e., Corn Belt, Northern Plains, Southern Plains, and Lake States), the regions recording the greatest increases were the Northern Plains (35 percent) and the Southern Plains (35 percent).

Phosphate use decreased in most regions between 1982 and 1992, except in the Northern Plains, where it rose 14.3 percent. Phosphate use dropped over 20 percent in the Pacific, Southeast, Lake States, and Corn Belt regions.

Nationally consistent 1982 to 1992 data to document the per acre applications of nitrogen and phosphate were available only for some crops. Results for corn, cotton, soybeans, and wheat are reported here. Figure 2-13 shows an overall decline in the national average application rate of commercial nitrogen to corn from 135 to 127 pounds per acre from 1982 to 1992. The 1992 range in rates varies from a low of 78 pounds per acre in South Dakota to 160 pounds per acre in Texas. Note, however, that this range reflects a large difference in corn yield: the Texas yield was 41 bushels per acre greater than the South Dakota yield. Figure 2-14 shows no significant trend in commercial phosphate application rates on corn over the period.

Figure 2-15 shows an irregular rise in the nitrogen application rate for all wheat—durum, winter, and spring—varieties. As with corn, application rates vary between States. For example, the 1992 rate for spring wheat varied from a low of 43 pounds per acre in South Dakota to a high of 86 pounds per acre in

Figure 2-12 Phosphate consumption, all applications, 1982 to 1992 (C. Lander, 1994a)

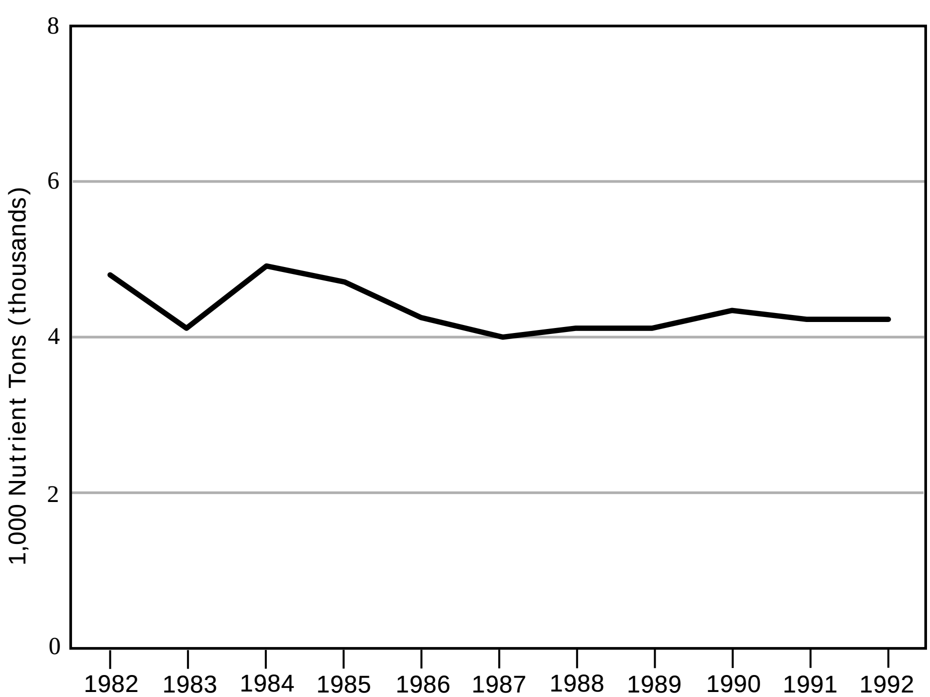


Table 2-6 Commercial nitrogen and phosphate consumption, all farm and nonfarm applications, by Farm Production Region, 1982 to 1992

	Nitrogen			Phosphate[1]		
	1982 (millions of tons)	1992 (millions of tons)	Change (percent)	1982 (millions of tons)	1992 (millions of tons)	Change (percent)
Northeast	326	299	+22.4	250	208	-16.8
Appalachia	679	718	+5.7	438	409	-6.7
Southeast	724	452	-37.6	342	179	-47.7
Lake States	1,086	1,119	+3.0	621	468	-25.6
Corn Belt	3,395	3,279	-3.5	1,606	1,269	-21.0
Delta States	530	674	+27.2	177	180	+1.7
Northern Plains	4,450	1,953	+34.7	505	577	+14.3
Southern Plains	959	1,192	+24.3	329	288	-12.5
Mountain	671	666	-0.8	262	270	+3.1
Pacific	951	829	-12.9	704	238	-66.2
Other	27	21	-22.3	12	10	-16.7
United States	10,798	11,301	+4.75	5,246	4,096	-22.0

Source: C. Lander, 1994a, RCA Nutrients Report, draft of 7-21-94.
[1]USDA is currently gathering nutrient use data on 36 crops, but these data have not been collected nationally since 1982. The Tennessee Valley Authority has been compiling and analyzing data received from State regulatory agencies on fertilizer sales for all (farm and nonfarm) purposes for the period 1982 to the present. The table draws on both the USDA and TVA data.

Figure 2-13 Nitrogen used on corn, rate per fertilized acre receiving nitrogen, selected States, 1982 to 1992 (C. Lander, 1994a)

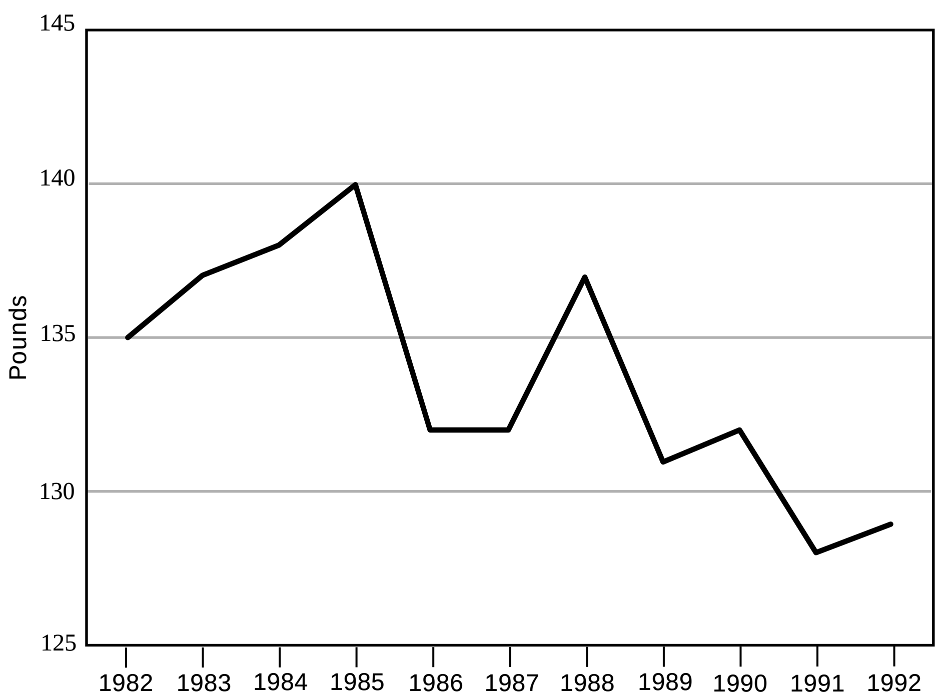


Figure 2-14 Phosphate used on corn, rate per fertilized acre receiving phosphorus, selected States, 1982 to 1992 (C. Lander, 1994a)

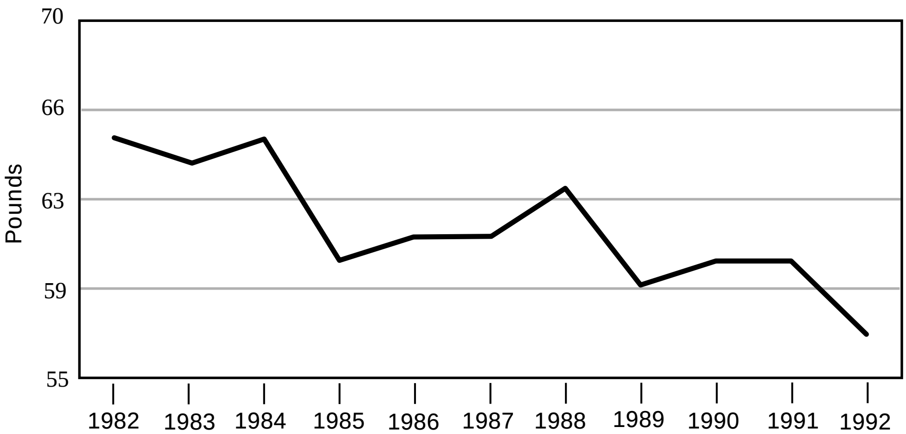


Figure 2-15 Nitrogen used on wheat, rate per fertilized acre receiving nitrogen, selected States, 1982 to 1992 (C. Lander, 1994a)

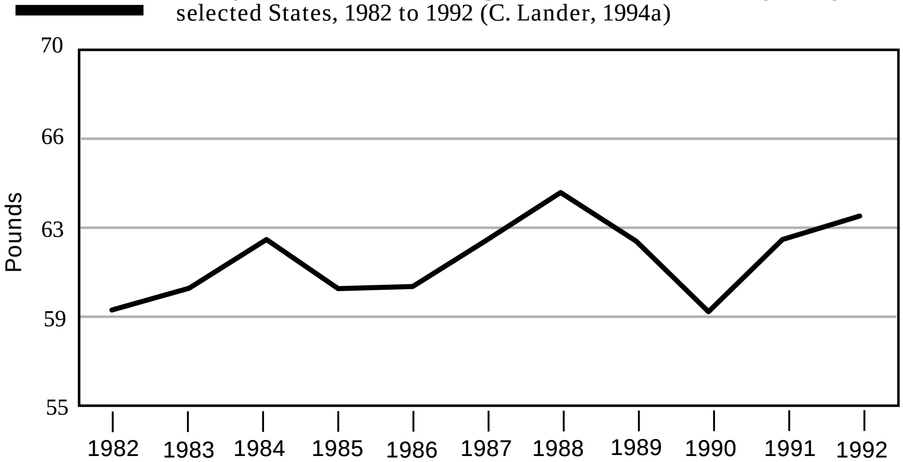
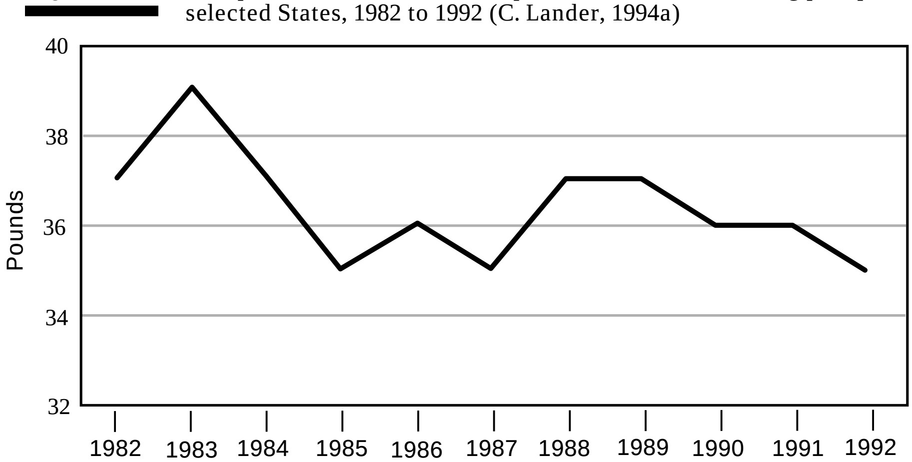


Figure 2-16 Phosphate used on wheat, rate per fertilized acre receiving phosphorus, selected States, 1982 to 1992 (C. Lander, 1994a)



Minnesota. Figure 2-16 shows an overall decline in phosphate fertilizer application rates. For example, phosphate applications on 1992 spring wheat varied from a low of 24 pounds per acre in South Dakota and Montana to a high of 34 pounds per acre in Minnesota.

Figure 2-17 suggests an upward trend in nitrogen fertilizer application rates from 1986 to 1992 for soybeans. Not all soybean acres are fertilized. From 1982 to 1992, fertilized acreage was 15 to 20 percent of the total acreage. The 1992 data show application rates ranging from a low of 12 pounds per acre in Indiana to a high of 44 pounds per acre in Kentucky. In 1992, the range in acreage fertilized was from 4 percent in Louisiana to 54 percent in North Carolina. In figure 2-18, the phosphate fertilizer application rate on soybeans mirrors that of nitrogen application. Application rates varied from 31 pounds per acre in Nebraska to 74 pounds per acre in Kentucky.

Figure 2-19 shows a marked change in nitrogen application on cotton—from a 1982 to 1986 downward trend to a strong upward trend thereafter. Application rates varied from a low of 66 pounds per acre in Texas to a high of 131 pounds per acre in California. Phosphate and nitrogen application rates on cotton are

Figure 2-17 Nitrogen used on soybeans, rate per fertilized acre receiving nitrogen, selected States, 1982 to 1992 (C. Lander, 1994a)

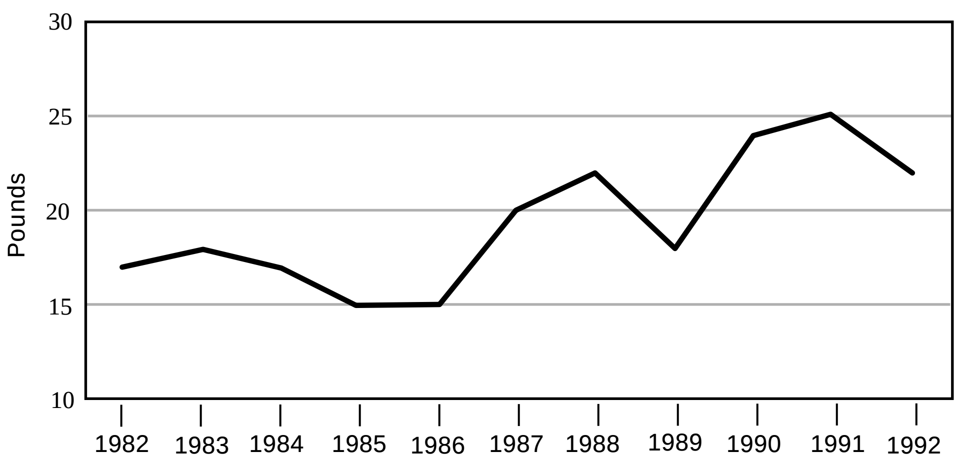
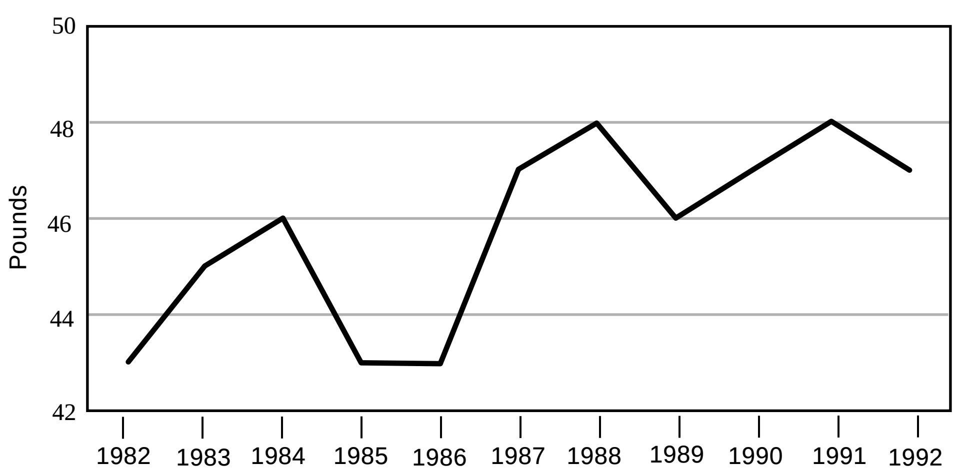


Figure 2-18 Phosphate used on soybeans, rate per fertilized acre receiving phosphorus, selected States, 1982 to 1992 (C. Lander, 1994a)



highly correlated. Application rates in 1992 vary from 44 pounds per acre in Arkansas, Louisiana, and Texas to 86 pounds per acre in California.

Animal manures

From 1982 to 1992, livestock numbers changed along with consumption patterns for meat products (table 2-7). Nationally, turkeys, chickens (broilers), and swine production increased 62.0, 59.0, and 5.4 percent, respectively, over the period. Beef cattle and dairy animal production dropped by 14.6 and 9.2 percent, respectively (Lander, 1994a).

Manure (fecal matter and urine) excreted by these animals contains significant quantities of nitrogen and phosphorus, a portion of which is available to the landowner for direct application to cropland. The remainder has already returned to the environment through losses occurring during collection, storage or treatment; or because the manure is produced where collection is not realistically possible (e.g., on grazing lands or pastures). The nitrogen available to the land owner for direct application ranges from 25 to 40 percent from swine, dairy, and beef cattle manures to between 50 and 60 percent for poultry. Phosphorus content of applied manure is much greater—an estimated 85 percent of that excreted by the animal (Lander, 1995).

In 1992, the manures from these animal populations contained an estimated 1.74 and 1.24 million tons of organic nitrogen and phosphorus, respectively, when applied to the land by farm operators. Cattle and dairy animals together accounted for 79.1 percent of the nitrogen and 82.5 percent of the phosphorus content, respectively (table 2-7). Broilers accounted for 17.2 percent of the nitrogen and 10.6 percent of the phosphorus.

Historically, producers have disposed of animal waste on their lands. Since the early 1980s, the livestock industry has moved toward greater regional animal concentration (table 2-7). In the major livestock production regions, the Southern Plains has increased its relative share of beef cattle; the Pacific, its share of dairy animals; and the Southeast and Delta, their shares of broilers. The Corn Belt continues to dominate swine production.

From a water quality perspective, the industry's movement from open grazing on large acreages to intensive animal confinement facilities and greater output levels per facility is significantly more important than changes in numbers and in total waste produced. Increasingly, the production facility has little access to owned or rented land for feed production or waste disposal. Because transporting large volumes of manure long distances is costly, the amounts disposed of per acre on nearby acreage must be quite large to accommodate concentrated operations. But the nutrients contained in the manure may exceed crop nutrient requirements, depending on the amount of nutrients lost while the manure was in storage, the per acre rates, and timing of application; the types, varieties,

Figure 2-19 Nitrogen used on cotton, rate per fertilized acre receiving nitrogen, selected States, 1982 to 1992 (C. Lander, 1994a)

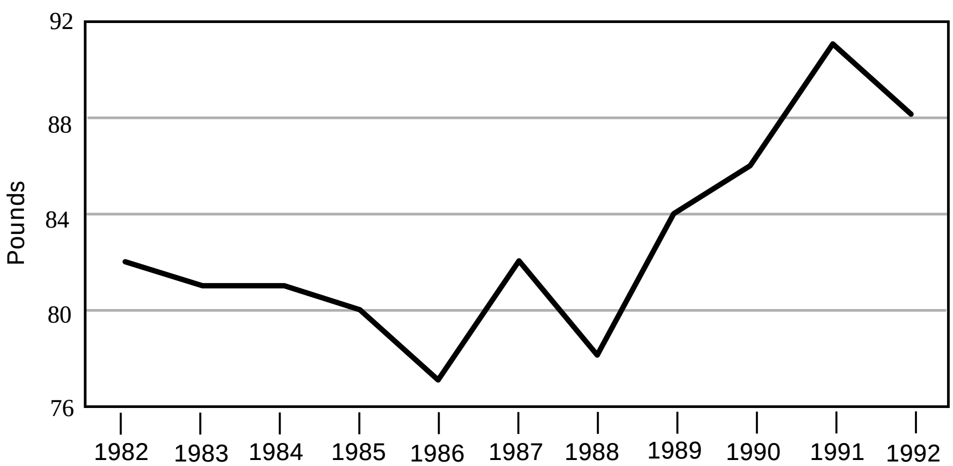


Table 2-7 Regional shifts in livestock numbers, 1982 to 1992, and nitrogen and phosphorus produced by livestock in 1992, by Farm Production Region

Region	Cattle and calves			Dairy animals		
	Change in numbers 1982 to 1992	1992 production		Change in numbers 1982 to 1992	1992 production	
		Nitrogen	Phosphorus		Nitrogen	Phosphorus
	percent	1000 tons		percent	1000 tons	
Northeast	-19.9	18.7	18.7	-16.3	92.4	27.0
Appalachia	-4.3	74.6	74.6	-21.5	31.6	9.2
Southeast	-16.6	54.9	54.9	-14.4	16.4	4.8
Lake States	-24.1	41.5	41.5	-11.1	140.0	40.9
Corn Belt	-28.0	123.0	123.0	-16.9	61.6	18.0
Delta States	-27.0	38.4	38.4	-28.3	9.7	2.8
Northern Plains	-12.1	166.9	166.9	-17.6	19.3	5.7
Southern Plains	-2.7	189.1	189.1	1.6	20.8	6.1
Mountain	NA	115.6	115.6	NA	20.6	8.4
Pacific	-21.6	53.0	53.0	-23.2	77.9	22.8
Other	-10.7	2.0	2.0	-30.4	0.6	0.6
United States		877.4	877.4		498.6	145.9

Region	Hogs and pigs (for market)			Chickens (broilers)		
	Change in numbers 1982-1992	1992 production		Change in numbers 1982-1992	1992 production[1]	
		Nitrogen	Phosphorus		Nitrogen	Phosphorus
	percent	1000 tons		percent	1000 tons	
Northeast	0.4	1.5	1.9	14.9	13.2	5.7
Appalachian	45.2	6.9	9.1	NA	47.0	20.5
Southeast	-26.0	2.1	2.7	79.2	95.3	41.7
Lake States	17.5	7.7	10.1	71.2	2.9	1.3
Corn Belt	0.3	32.2	42.3	NA	7.8	3.4
Delta States	13.2	8.8	11.5	56.1	70.9	30.9
Northern Plains	12.4	1.1	1.4	28.2	0.1	0.1
Southern Plains	0.6	0.8	1.1	89.1	24.3	10.6
Mountain	8.5	1.0	1.0			
Pacific	14.0	0.4	0.5	44.1	13.7	6.0
Other	-30.2			-34.6	7.6	3.3
United States		62.4	81.6		299.9	130.9

Source: C. Lander 1995

[1] In addition to the manure nutrients produced by broilers, laying chickens produced an estimated 0.11 million tons and 0.07 million tons of nitrogen and phosphorus, respectively, in 1992. Turkeys produced 0.12 million tons and 0.07 million tons, respectively, in 1992.

NA = Not available

and extent of the fields; weather; conservation practices; and soils. Some nutrient losses into water will occur whether the application rates exceed crop and soil assimilative capacities or not.

Potential nitrogen and phosphate loss from farm fields

The amount of nitrogen and phosphorus from commercial fertilizer applications that could potentially be available for runoff or leaching was estimated to show which areas of the country had the greatest potential for water quality problems related to nutrient loss from farm fields (Figure 2-20). Estimates were made by combining data on land use for 1992 from the National Resources Inventory (NRI) with data on commercial fertilizer use and crop yields from the National Agricultural Statistics Service. The NRI is a national survey of land use and soils characteristics that is based on about 800,000 sample points, 300,000 of which are on cropland (Kellogg et al.1994).

The calculation is based on the assumption that when crops take up less nutrients than are available from the amount applied, the excess is potentially available for leaching and runoff. State data on nutrient application rates and percent of acres treated were assigned to the NRI sample points according to the state and the crop grown. Crops included corn, soybean, wheat, cotton, barley, sorghum, and rice. A per-acre estimate of pounds of excess phosphorus and nitrogen was calculated for each 1992 NRI sample point as the difference between the rate of application per treated acre and the amount of nitrogen and phosphorus estimated to be taken up by the crop and removed from the field at harvest. The amount of nutrients taken up by the harvestable portion of the crop was estimated by multiplying the percent of nutrients in the harvested portion (Lander, pers. comm.) times the county per-acre yield. Since yields can vary dramatically year to year, a five-year average yield was used to determine county yield for 1988-1992. Phosphorus and nitrogen from animal wastes are not included in these estimates.

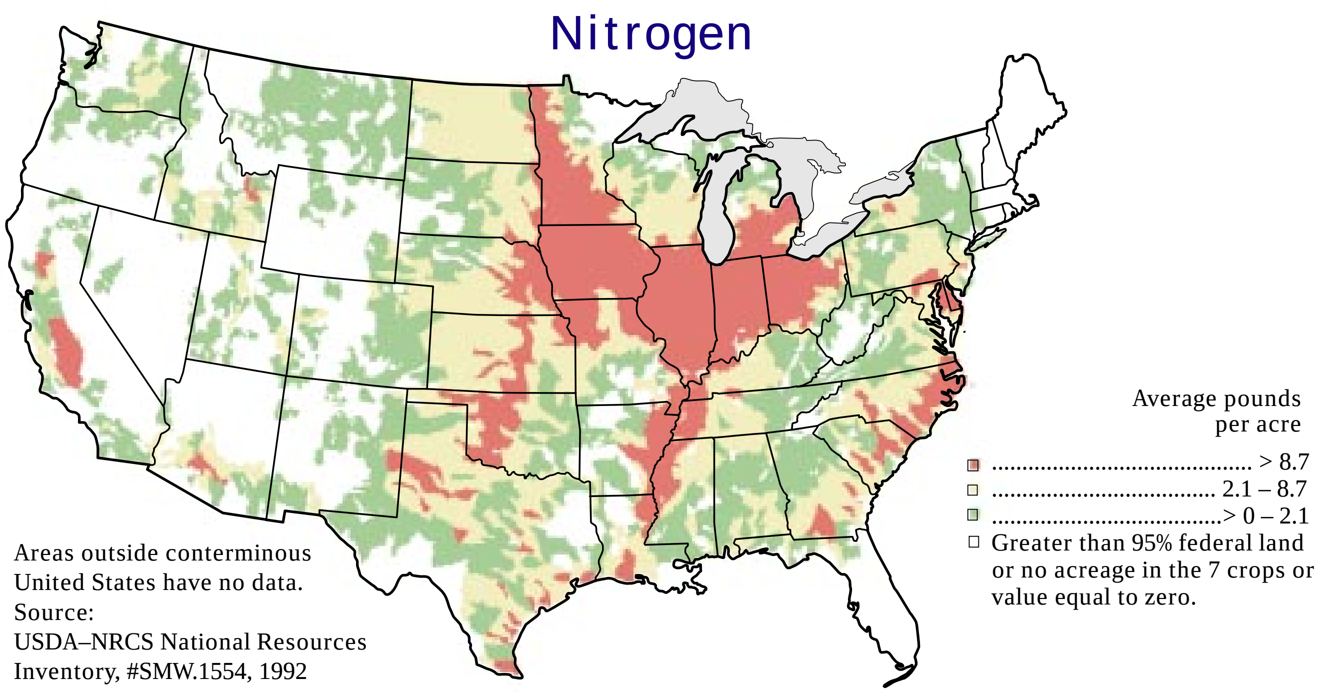
For nitrogen, an additional adjustment was made for legumes grown in the previous years. If the previous legume crop was soybeans, 1 pound of nitrogen credit was assumed for each bushel of soybeans harvested. If one crop of alfalfa existed during the previous 2 years, the nitrogen credit was 90 pounds per acre. If alfalfa crops occurred in the previous 2 years, the nitrogen credit was 135 pounds per acre. Cropping history for the two years prior to 1992 was obtained from the NRI.

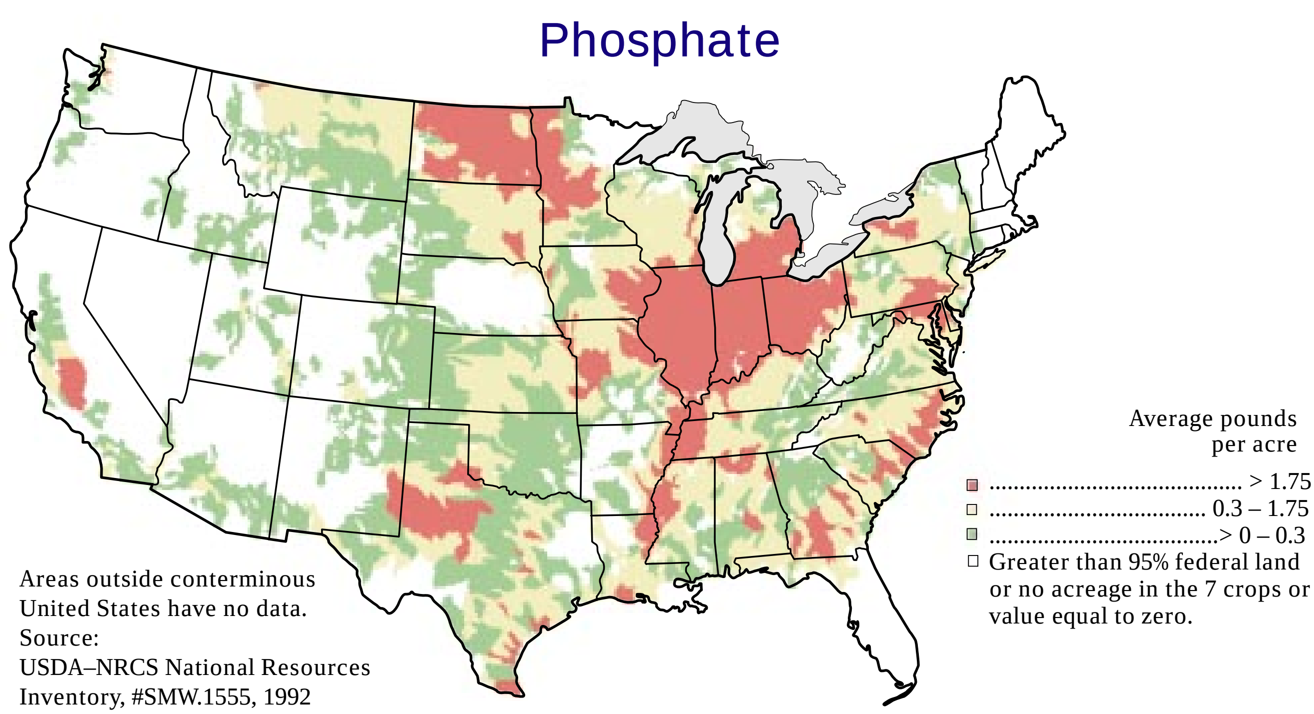
The average per-acre rate for the watershed was determined by dividing the excess phosphorus and nitrogen loadings per watershed (accounting for the percent acres treated) by the total acres of nonfederal rural land in the watershed. Dividing by the acres of nonfederal rural land provides an overall watershed level perspective of the significance of the excess nutrients in terms of the potential to degrade other environments if the nutrients migrated from the farm field. Consequently, watersheds with only a few acres of the 7 crops will generally not score very high, whereas watersheds with a high proportion of the watershed in the 7 crops and where nutrients are applied in amounts greater than amounts removed in the harvest would score high.

Red areas of the map include 25 percent of the watersheds with the highest scores. Watersheds with the highest levels of excess phosphorus from these 7 crops occur in the Midwest (Illinois to Ohio), North Dakota and northwest Minnesota, parts of Texas, and scattered watersheds along the Atlantic coastal plain. Nitrogen available for leaching or runoff is highest in many of the same areas where excess phosphorus loadings are high. Differences occur in South Dakota, where excess nitrogen is much less than excess phosphorus, and Iowa, southern Minnesota, and eastern Nebraska, where excess nitrogen is much greater than excess phosphorus.

These estimates reflect the amounts of applied nitrogen and phosphate fertilizer that are not taken up by the harvested crop and, as such, *may* be available for loss to the environment. Not all of these materials will actually move from the field, however. Both nitrogen and phosphorus may be immobilized in the soil or managed in some other way by producers to reduce the potential for loss to the environment. Whereas nitrogen is highly mobile, phosphorus may build up in soils. But both can move from farm fields into surface water and ground water, sometimes causing significant environmental impacts.

Figure 2-20 Potential nitrogen and phosphate fertilizer loss from farm fields





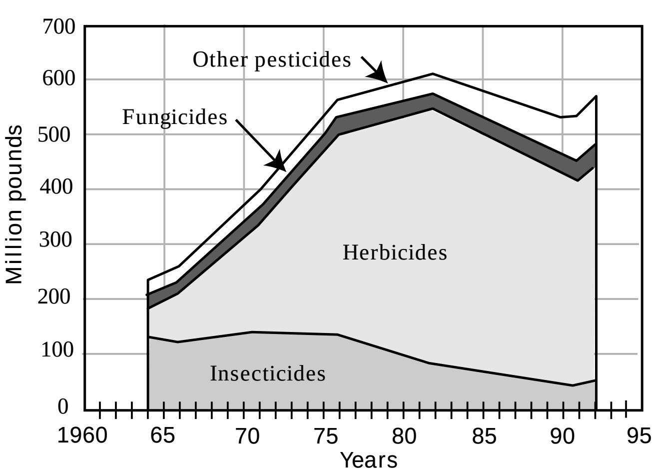
Pesticides

U.S. agriculture spends about $6 billion annually on pesticides, thereby accounting for about 75 percent of all pesticides sold. Nonagricultural uses of pesticides, the remaining 25 percent, include home, lawn, and garden use; industrial use; pest control in forestry; weed control along roadsides and ditches, pest control by municipalities and local governments, golf course uses, and military use.

Pesticide use

In agriculture, pesticides are used to protect food and fiber from damage by insects, weeds, diseases, nematodes, and rodents. Herbicides are used on more than 90 percent of corn, cotton, and soybean acres (Lin et al. 1995). Insecticides are used on 30 percent of corn acres, 65 percent of cotton acres, and 90 percent of potato acres. Fungicides are used extensively in peanut and potato production and for most fruits and vegetables. Nevertheless, pests still destroy nearly 13 percent of all potential food and fiber crops in the United States. Without pesticides, the retail prices of food and fiber would increase substantially, and their availability would fluctuate from year to year. Crop losses from weeds alone are estimated to be worth an average of $4.1 billion per year.

Figure 2-21 Pesticide use on selected crops, by pesticide type, 1964 to 1992 (Lin et al. 1995)



Selected crops include corn, cotton, soybeans, wheat, sorghum, peanuts, rice, potatoes, other vegetables, fruit, and nuts.

Pesticide use increased from 1964 to 1982, largely because of rapid growth in the use of herbicides (Figure 2-21). Pesticide use on corn, cotton, soybeans, wheat, rice, sorghum, peanuts, potatoes, other vegetables, citrus, and apples ranged from roughly 533 to 564 million pounds between 1990 and 1992, about a 10 percent decrease from 1982. These crops account for about 60 percent of the 886 million pounds of pesticides (active ingredient) used in agriculture each year (Gianessi and Anderson, 1995).

During the 1960s, agricultural pesticide use was dominated by insecticides. Today, herbicides make up 70 percent of the quantity of pesticides used in agriculture. By a substantial margin, corn leads all other crops in total pesticide use. Rice, potatoes, vegetables, and fruits also use pesticides intensively.

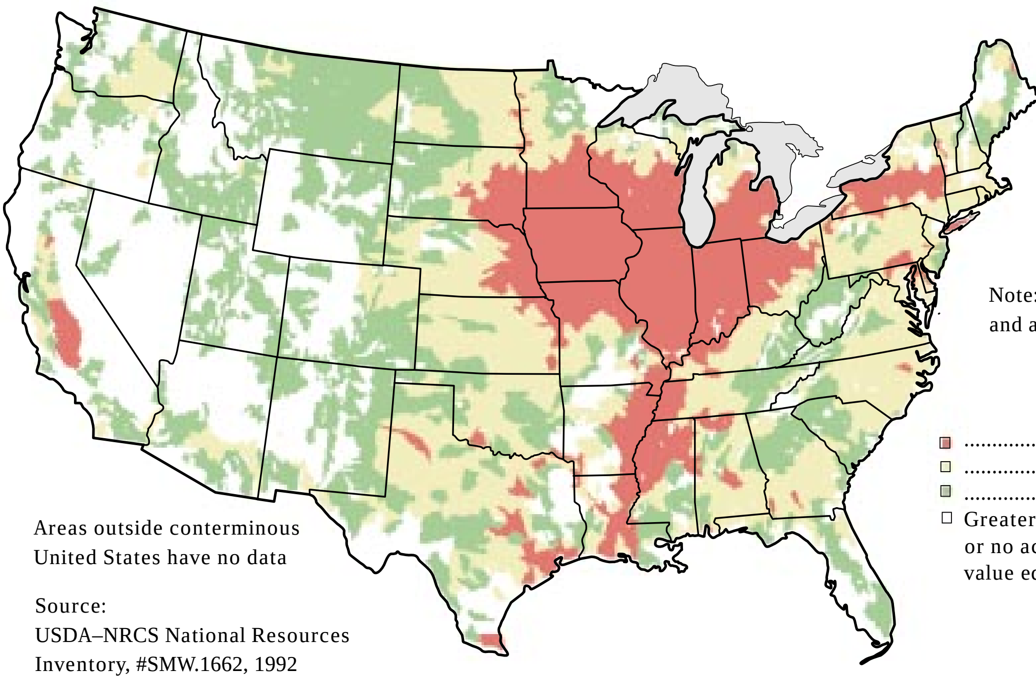
Seven herbicides (atrazine, metolachlor, alachlor, 2,4-D, cyanazine, trifluralin, and pendimethalin) comprise two-thirds of all herbicide use and one-third of all pesticide use. Nearly 72 million pounds of atrazine is used annually by agriculture. The fungicide most commonly used was sulfur (83 million pounds); the most commonly used insecticide was oil (51 million pounds).

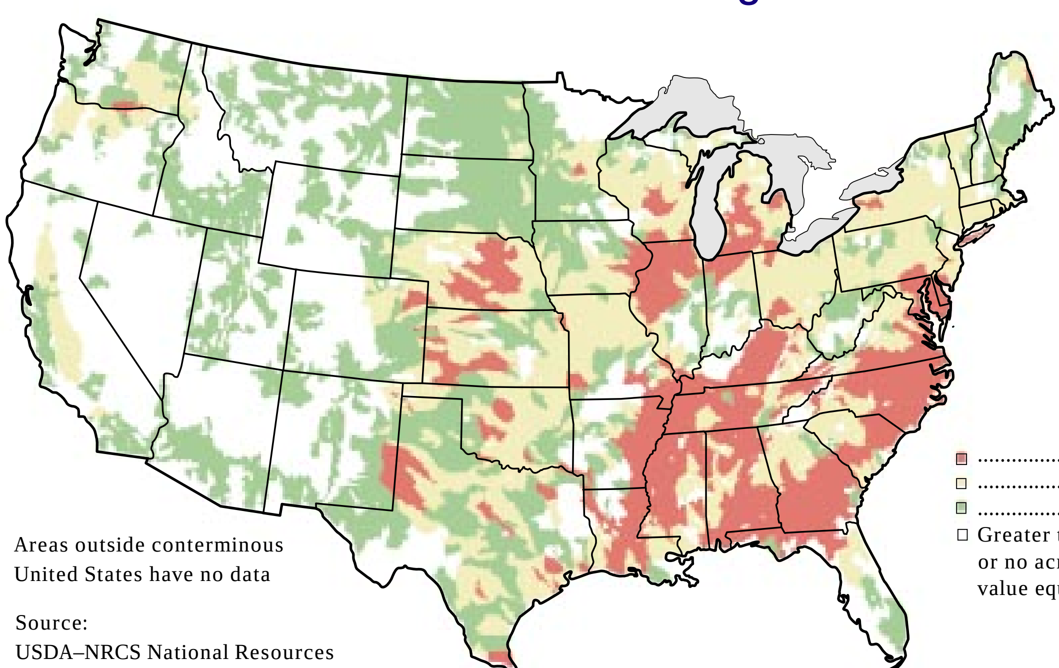
Potential for pesticide loss from farm fields

Even when the label instructions are carefully adhered to, a small portion of pesticides applied on farms sometimes reaches surface and ground water, as evidenced by the detection of pesticides in water quality monitoring studies. Pesticide loss from farm fields depends on the natural characteristics of an area (soil properties, climate, and terrain), properties of the chemicals used, and farm management practices. The relationships among these factors are complex. Pesticides that leach or run off on one soil type may not significantly leach or run off with another soil type.

To devise and implement policies for reducing pesticide losses from farm fields, decision-makers need to know where in the country the potential for these

Figure 2-22 Pesticide runoff and leaching potential for field crop production





losses is the greatest. Using national-level databases, a simulation was conducted of potential pesticide losses from farm fields on the basis of the factors that are known to be important determinants of pesticide losses, including

1. intrinsic potential of soils to leach or runoff pesticides.
2. chemical properties of the pesticides.
3. annual rainfall and its relationship to leaching and runoff.
4 cropping patterns.
5. chemical use.

Annual pesticide losses were estimated by Don Goss (Texas Agricultural Experiment Station, Temple, Texas) for a variety of soils and climates using the field-level process model GLEAMS (Groundwater Loading Effects of Agricultural Management). Leaching and runoff estimates were generated for 240 pesticides applied to 120 soils for 20 years of daily weather from each of 55 climate stations distributed throughout the United States. Pesticide runoff was movement beyond the edge of the field, including both pesticides in solution and pesticides adsorbed to soil material and organic matter. Pesticide leaching was movement beyond the bottom of the root-zone. Separate estimates were made for irrigated and nonirrigated conditions.

These pesticide loss results were then integrated with a national chemical use database and the 1992 National Resources Inventory (NRI) to simulate potential pesticide loss for cropland throughout the conterminous United States. NRI sample points were treated as “representative fields.” Land use data for 1992 was used. Thirteen crops were included in the simulation: barley, corn, cotton, oats, peanuts, potatoes, rice, sorghum, soybeans, sugar beets, sunflowers, tobacco, and wheat. Fruits, nuts, and vegetables were not included in the simulation because the NRI does not include data on specific crops for these categories. Estimates of percent of acres treated with pesticides and application rate by crop and by state were obtained from Gianessi and Anderson (1995) for over 200 pesticides. These estimates represent average chemical use for the time period 1990–93. Pesticide use was imputed to NRI sample points on the basis of the crop grown and the state in which the NRI sample point was located.

The potential for pesticide loss from each “representative field” was estimated using the state average application rate, percent of acres treated, and the percent of annual pesticide loss estimates. The maximum percent of leaching and runoff loss over the 20-year period was imputed to NRI sample points using matchups by soil and proximity to the 55 climate stations. The total loss of pesticides from each “representative field” was estimated by summing over the loss estimates for all the chemicals that could have been used on the crop grown on the “representative field,” after adjusting for the percentage of the acres treated. Average watershed loadings were obtained by aggregating the pesticide loss over all the “representative fields” in the watershed where one of the 13 crops were grown using the NRI expansion factors as weights, and then dividing by the acres of nonfederal rural land in the watershed.

The results of the simulation are shown in figure 2-22. Red areas of the maps include 25 percent of the watersheds with the highest scores. The potential for pesticide runoff loss on a per-watershed basis is greatest for watersheds in the Midwest and the Mississippi Embayment. The potential for pesticide leaching loss is greatest for watersheds along the Atlantic Coastal Plain and the Mississippi Embayment and some watersheds in the Great Plains. These leaching losses not only affect groundwater quality, but also affect surface water quality through groundwater return flow to rivers and streams, especially during low flow periods.

The maps show how the potential for pesticide loss varies around the country, assuming general chemical use practices and cropping patterns. Actual pesticide loss will differ from these simulated results because of the wide variety of application rates that farmers use, changes in the crops grown since 1992, and the management practices in use. Research has shown that, with proper management, most of the potential for pesticide loss can be eliminated. Crop residue, for example, affects the water-holding capacity of the soil and thus the movement of water that carries the pesticides from the field. Organic matter content of the soil can be increased with appropriate management practices, thus increasing the sorption of some pesticides onto soil particles and retaining them in the soil long enough for degradation by chemical and biological processes. Conservation tillage can reduce the soil loss from the field and thus reduce loss of pesticides adsorbed to the soil particles. The potential pesticide loss shown in the maps does not adjust for reduction in losses resulting from these management practices. The maps do show, however, where in the country the need for careful farm management is the greatest, and where the likelihood of water quality impacts from pesticide loss from farm fields is the greatest.

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Chapter 3 Complexity of Measuring Water Quality

A statistical description of national water quality conditions and trends is inherently limited, since reliable national data do not yet exist for many aspects of water quality[1]. Water quality monitoring, like most environmental monitoring, is technically demanding and expensive. In addition, over the past 20 years, ideas have changed about which water quality indicators are important and how to measure them.

Monitoring objectives

The critical need to develop objective and nationally consistent time-series data and information on water quality prompted a group of 20 Federal, State, and interstate agencies to establish the Intergovernmental Task Force on Water Quality Monitoring (ITFM). ITFM evaluates the status of monitoring in the United States, which it defines as follows:

> *Water quality monitoring is . . . an integrated activity for evaluating the physical, chemical, and biological character of water in relation to human health, ecological conditions, and designated water uses. It includes the monitoring of rivers, lakes, reservoirs, estuaries, coastal waters, atmospheric precipitation, and ground waters (ITFM, 1992).*

A more task-oriented definition focuses on collecting water samples in the field and on subsequently analyzing them in the laboratory to produce quantitative information on conditions at specific locations and times of sampling. This definition assumes that all monitoring includes a systematic plan for managing and analyzing the results of field and laboratory procedures.

A key aspect of monitoring not covered in these definitions is its recurrent nature. Monitoring implies a continuing series of observations, over some time period, some range of locations, or both. Monitoring is not a one-time look at conditions at one location.

Monitoring objectives vary greatly but nearly all can be placed in one of five categories (ITFM, 1992):

- defining status and trends,
- identifying existing and emerging problems,
- providing information to support policies and programs underlying water resource management,
- evaluating program effectiveness, and
- responding to emergencies.

The ITFM definition of water quality monitoring speaks broadly about evaluating water in relation to human health, ecological conditions, and designated water uses. A subsequent section of its first year

[1]*Material in this chapter was prepared by TVA's Neil Carriker, chair of the ITFM Work Group on Assessment and Reporting.*

review states that “monitoring is a means for understanding the condition of water resources and providing a basis for effective policies that promote the wise use and management of this vital resource” (ITFM, 1992).

This link with resource management policies is critical; it explains why water quality monitoring is important to agricultural issues. Monitoring helps determine the policies and programs needed to protect and improve our Nation’s streams, rivers, and lakes. It provides the basis for prioritizing among watersheds and farms so that limited resources are effectively allocated to improve conditions in the streams and lakes that drain them. Finally, monitoring is essential to evaluate whether resource management policies and programs actually result in measurable environmental improvements and to identify what changes are needed to make them more effective.

Agricultural water quality monitoring

Using water quality monitoring to identify problems, establish trends, and detect changes in water affected by nonpoint source pollution is rarely simple. For one thing, we have less experience in nonpoint source monitoring than in identifying point sources or quantifying lake and stream recovery after improvement of waste treatment. And it is often hard to make a direct link between land management practices and the conditions observed in streams and lakes. Except in very small watersheds, multiple land uses are usually present above a monitoring site, and point sources are often present as well. Therefore, distinguishing the effects of different stressors is difficult.

The quality of nonpoint source pollution is difficult to characterize because it varies greatly over short periods. Pollutant concentrations in runoff during the first 10 minutes of a storm event differ significantly from those in the next 10 minutes, and concentrations will continue to change throughout the event. Even in the same watershed or field, concentrations will vary from storm to storm, depending, for example, on the length of time since the last rain, the duration and intensity of rainfall, whether agricultural chemicals have been applied to the land, whether the soil has been tilled, and the season.

Identifying the effects of nonpoint source pollution on streams and lakes may be easier than characterizing the quality of runoff. But even that is no simple task. It requires a carefully developed plan to collect enough right data at the right places over an appropriate time period. “Enough data” includes considering the number of locations, the frequency of collection, and the duration of sampling. “The right data” usually means physical and chemical information on water, sediments, and sometimes biological tissues, and information on one or more components of the biological community (fish, aquatic insects, algae).

These data must usually be collected at two locations — where impacts are suspected and where no impacts are expected. Wherever possible, the best way to evaluate nonpoint source impacts is by simultaneously monitoring paired watersheds where the principal difference is a land management practice. The “appropriate time period” depends entirely on the specific monitoring objectives. It may be as short as a few weeks during the growing season for a paired watershed approach or as long as six to eight years for some types of trend analysis. And even the best plans may be compromised by extreme weather conditions or other uncontrollable factors.

These limitations may seem overwhelming, but they do not preclude effective nonpoint source monitoring. Plans for monitoring the effects of agricultural practices or other land management activities must recognize these limitations and the risks associated with nonpoint source monitoring. Through such recognition, safeguards can be incorporated into the monitoring design to ensure that useful information is collected, regardless of circumstance.

Monitoring approaches

For some nonpoint source water quality monitoring applications, collecting information on water contaminants is sufficient. In most cases, however, the water and at least some biological community should be examined. Because of significant temporal variability in runoff quality, discrete water samples collected at discrete points in time may not adequately describe the ecosystem's exposure to contaminants. Continuous samples that integrate water chemistry over the sampling period help ensure that the data are representative, though each sample is unique. General information on water chemistry and chemical contaminants is important but may not reflect the significance that transient events have on streams and lakes.

Examining biological communities and sampling sediments will help fill this gap. Sediments are the final repository for most pollutants introduced into waterways. They provide a historical record of conditions for many variables, particularly metals and organic chemicals resistant to biological degradation. Various pesticides and other toxic chemicals that resist degradation accumulate in sediments. Therefore, water extracted from sediments can be analyzed to determine its toxicity to aquatic insects and other organisms that normally live in the environment. This analysis, combined with chemical analyses of sediments and pore waters and evaluation of the aquatic insect community, can provide useful information on the types of pollutants in the water and their effects on the ecosystem.

Fish, plants, and aquatic insects integrate pollutant exposures over time. Their recoveries from transient events that cause major stresses on the ecosystem are usually slow and vary among types of biological community. Sampling these biological indicators can help us detect transient events missed by discrete water sampling; it will also provide clues about the magnitude of the stress and the type of pollutant.

Primary contaminants

Agricultural water quality monitoring is particularly interested in five categories of water contaminants: sediments, nutrients, bacteria, pesticides, and dissolved solids that rapidly deplete oxygen from streams. Each of these contaminants is related to specific agricultural practices or activities, and each has specific effects on lake and stream quality. In some situations, runoff from agricultural lands may be the major source of contaminants. In other situations, runoff from cities, residential areas, mined lands, construction sites, or municipal or industrial wastewater discharges may be major sources. Discriminating among contaminant sources and evaluating their relative contributions to ambient stream or lake conditions form the challenge of water quality monitoring. Chapter 2 discussed sediments, nutrients, and pesticides in detail. Bacteria and oxygen depletions should also be monitored.

Animal wastes are a source of bacterial contamination. Fecal wastes from farm animals—as from humans—contain high concentrations of many types of bacteria. If accidentally ingested in drinking water, some bacteria will cause disease, and human contact with the contaminated water can result in infections in open wounds or in sensitive tissues, such as the eyes, ears, and nasal passages.

Oxygen dissolved in streams and lakes is essential for fish and other desirable organisms. The amount present reflects a balance between processes that add oxygen to the water, processes that remove it, and water's inherent capacity to dissolve oxygen, which varies with temperature. The chemical oxidation of inorganic compounds like ammonia and the biochemical oxidation of organic compounds are the main processes that deplete oxygen from streams and lakes. Large amounts of organic detritus from decaying crops or manure and excessive ammonia and other inorganic chemicals from fertilizers or manures can cause dissolved oxygen levels to fall quickly below levels needed for fish. Algal blooms — rapid, abundant growths of algae resulting from nutrients washed into the water — tend to die off quickly and their decomposition also depletes the oxygen supply.

Potential variables

Each category of contaminants has several variables that can be measured to determine the level of contamination or its effect on the ecosystem. Some variables directly measure the concentrations of specific contaminants. Others are operationally defined variables that relate more to processes than to specific contaminants. Some measure the levels of indicator or surrogate variables; still others focus on the effects of contaminants on the ecosystem.

Variables used to measure sediment content in stream and lake water samples typically include turbidity, total suspended solids, and particle size distribution for suspended particulates. The most common of these are turbidity and total suspended solids. In lakes and large rivers, Secchi depth is frequently used as a measure of water clarity. To obtain this measurement, a black and white disc is lowered into the water until it can no longer be seen. Sediment depth is also physically measured in some situations.

Several nutrient variables are commonly measured. For phosphorus, the most common variables are total phosphorus (determined after an exhaustive chemical oxidation), total reactive phosphorus (measured in unfiltered, undigested samples), total soluble phosphorus, and soluble reactive phosphorus. Total phosphorus attempts to measure all phosphorus that might eventually be available to stimulate plant growth. Reactive phosphorus measurements quantify levels of orthophosphate phosphorus readily available for plant uptake.

Nitrate-plus-nitrite nitrogen and ammonia nitrogen directly measure inorganic nitrogen forms available for plant growth. Kjeldahl nitrogen, which involves an exhaustive chemical digestion of organic compounds in the water, measures a combination of organic nitrogen and ammonia. Organic nitrogen, calculated by subtracting the ammonia value determined on an undigested sample, essentially measures the nitrogen amount locked up in the proteins of algae, zooplankton, and fecal wastes in the water. Total nitrogen is the sum of all inorganic and organic forms.

Fecal coliform bacteria is the most common bacterial variable measured. Fecal coliform organisms are present in the guts of all warm-blooded animals. Fecal coliforms are normally not pathogenic. However, their presence indicates that disease-causing bacteria from fecal matter are likely present. Analyzing samples for fecal coliforms is easier and cheaper than for specific pathogens.

Analyses of specific herbicides, insecticides, or other similar chemicals are direct measures of pesticide contamination of water, sediments, or biological tissues. Toxic substances are also identified by growing cultures of certain biological test organisms in ambient water samples or in the presence of stream and lake sediments. These bioassays can be used to determine a contaminant's effects on reproduction, mutation, or survival. Different procedures are used to evaluate chronic and acute exposures of test organisms, and several different types of test organisms are used.

The presence of oxygen-demanding materials is measured both by observing their effects on dissolved oxygen levels in ambient waters and by operationally defined direct measurements. Directly observing dissolved oxygen, either through a single instantaneous measurement or a series of measurements over a specified time, provides useful information on the balance between oxygen consumption and oxygen production processes in a waterway.

The operationally defined variables, biochemical oxygen demand and chemical oxygen demand, attempt to directly measure the total amount of various contaminants that require oxygen for biochemical decomposition or chemical oxidation.

As previously described, biological community measurements generally assess a waterbody's ecological health. As they measure how biota respond to various conditions, they can detect episodic or continuing contamination and identify the extent of recovery from such perturbations. The biological communities most often monitored are fish, aquatic invertebrates (mainly aquatic insect larvae), and free-floating algae. Rooted aquatic plants and attached algae are sometimes monitored, but less frequently.

Biological monitoring results are commonly summarized in some type of multivariate index. Several indices have been developed, most with several common characteristics. Each index usually includes some measurement of the total number of species present (greater numbers of species generally mean better conditions), the diversity of organisms among species (a more even distribution among species is better than dominance by one or two species), the presence or absence of specific pollution-sensitive or pollution-tolerant species, and indications of stress (e.g., presence of disease, hybridization, absence of long-lived species).

Most indices include some evaluation of trophic structure, either in the diversity measurement or by grouping variables to represent different trophic levels. The most common indices currently in use are modifications of a fish community index of biotic integrity and corresponding aquatic insect community indices (benthic index of biotic integrity, stream community index, Hilsenhoff biotic index, and others).

Important ancillary variables

In addition to the chemical and biological variables previously described, a number of variables are important to a proper interpretation of water monitoring results. Water temperature is important to nearly all chemical measurements because it affects solubility and reaction rates. In particular, ambient water quality monitoring requires determining not only the level of dissolved oxygen, but also the percent of saturation as compared to the maximum amount that could be dissolved in the water at that time. Temperature also controls biochemical reaction rates. But more important from a biological perspective, in the course of evolution most aquatic species have developed requirements for specific temperature ranges. If water temperatures are outside those ranges, the species will be stressed, even to the point of death. At a minimum, mobile species will avoid areas with temperatures that cause stress.

Streamflow is important, particularly if one objective is to determine the flux of a particular contaminant passing the checkpoint. Without quantitative information on streamflow, this calculation is impossible. Even when flux measurements are not critical, qualitative flow information is useful in interpreting both chemical and biological data. Many physical and chemical variables are correlated with flow; thus, flow information is a useful check on the soundness of the results.

Habitat observations are particularly important in interpreting biological results. The presence or absence of important components of the aquatic biological community, or of specific indicator species, may depend more on suitable physical habitat than on the presence of chemical stressors. Similarly, high levels of turbidity may be more closely related to eroding streambanks immediately upstream from the sampling site than to whether adjacent agricultural lands are being properly managed.

Other important ancillary observations include the amount of recent rain, recent activities on adjacent lands (e.g., tillage, or fertilizer and pesticide applications), evidence of animal access to the waterway, air temperature, and amount of solar radiation.

Design of monitoring programs

Many factors affect the design of a water quality monitoring effort for agriculture. First to be determined are questions about specific monitoring objectives, the spatial and temporal scopes involved, and primary audiences for the results. The designer must also determine whether previous studies are relevant and assess the level of resources—money, personnel, and expertise — needed to ensure an effective program. Sometimes regulatory or legal requirements must also be considered.

The most important question is undoubtedly the purpose of the monitoring. Without clear objectives, most monitoring programs are doomed. At best, they waste resources by collecting more data than needed or not enough to address relevant questions. The objectives of most agricultural water quality monitoring programs fall under either "defining status and trends" or "evaluating program effectiveness," as defined by the ITFM. A biological survey of streams draining several watersheds of roughly equal size in the same river basin is an example of a status-oriented monitoring program. Its results could be used to select a few streams for more intensive monitoring or to prioritize watersheds for implementing improved agricultural management.

Monitoring at selected sites before, during, and following the installation of best management practices evaluates the effectiveness of the program that funded the practices. But to fully evaluate program effectiveness, similar monitoring is necessary at a comparable control location, either in the same watershed or in a watershed with the same mix of land uses. Results from the control site establish background trends and year-to-year climate variations to compare with trends at the test stations.

Clear articulation of the objectives of a monitoring program helps identify the frequency, duration, and spatial extent necessary to answer relevant questions and the variables that must be measured. The next step — after defining objectives and selecting stations, frequency, and variables to measure — is to examine results from previous studies.

Sometimes relevant earlier studies provide information about planning, but not about results because planning a monitoring program is much easier than actually carrying it out, and even that is usually less complex than interpreting the results. But in some cases, results already available can help identify pitfalls to avoid, and may even directly address the question.

At this point in the design, we need to consider who will use these results. Monitoring simply for the sake of documenting conditions may be useful, but it is not cost effective. For monitoring results to influence how funds and people are deployed to fix problems, they must be transmitted to decisionmakers quickly in an easily understandable form.

Now is also a good point to pause for a reality check: Are the available resources sufficient for this program? Must the objectives be narrowed? Are the right questions being asked? Objective evaluation of these and similar questions can lead to significant design changes that will increase the probability of success. Sometimes those changes are small but significant; but sometimes the whole monitoring program will need to be redesigned, starting with the objectives.

Properly designing an agricultural water quality monitoring program is not a simple task, but neither is it impossible. Carefully considering these factors will result in an effective, efficient monitoring program that focuses on relevant questions.

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USGS National Water Quality Assessment

Recognizing that the lack of water quality data has made comparing water quality within and between regions over time extremely difficult if not impossible, the U.S. Geological Survey (USGS) moved to a full-scale National Water Quality Assessment (NAWQA) program in 1991. The goal is to describe in a sound, scientific manner the status and trends in quality of a large, representative part of the Nation’s streams and ground water (Leahy et al. 1994).

The program will intensively study 60 to 70 percent of the Nation’s total water use and population served by public water supply. Investigations are now underway in 40 study units; 60 study units will eventually be covered. Results will be integrated into a regional and national syntheses on specific water quality issues. Initial syntheses focus on pesticides and nutrients and address the following questions: What are the concentrations of each pesticide or nutrient in selected river basins and aquifers? What is the relation of their concentrations in surface and ground water to natural factors and land management?

Chapter 4 A States-Based Snapshot — Surface Water

In 1987, Congress amended the 1972 Clean Water Act (CWA) to stress achieving interim water quality levels, known as “fishable and swimmable” goals. To comply with section 305(b) of the CWA, States must biennially report their progress toward these goals to EPA. EPA assembles these data into major reports of which the *National Water Quality Inventory: 1994 Report to Congress,* is the most recent. This report is frequently used for information on national levels of surface water impairment and the major causes and sources of that impairment (U.S. Environ. Prot. Agency, 1995). The 1994 report is based on state-reported 1992 and 1993 data. It provides a snapshot of the quality of each State’s assessed waters.

EPA finds it impossible to aggregate the States’ information into an accurate statement of national conditions and trends. Therefore, EPA does not expand State-developed data to national status or trends summaries with any known level of statistical confidence. The agency clearly identified several critical issues:

- Each State reports water quality based on the degree that its rivers, streams, lakes and estuaries support the State’s designated uses for a particular water body. All States follow EPA’s set of use support categories — fully supporting, partially supporting, or not supporting a particular water use. However, each State has its own criteria for designating the major uses of a water body and for determining which support category is appropriate. These different criteria result in inconsistent reporting across States. In fact, two States having one water body as their common border may designate different uses and use supports.

- States differ greatly in deciding what proportion of their water to assess and report, partly because of the varying importance that each State assigns to water quality. For example, just one State (of those States reporting siltation to be a problem in rivers and streams) accounted for one-third of all rivers and streams for which siltation is the leading cause of impairment.

- States, at their discretion, may or may not include previously assessed water in each biennial EPA reporting cycle, and their procedures for determining the proportion of their water to report may or may not be done in a statistical manner.

- As States learn more about the nature of their water quality problems, they also change their standards for rating water quality.

While the 305(b) report does not present a national statement of water quality condition or trends, it does provide a snapshot of water assessed by the States. The report is highly important for additional reasons:

- The report focuses on State-identified values with respect to water quality. That is, it focuses on each State’s key uses of specific waterbodies, the degree to which these uses are impaired, the specific pollutants causing the impairment, and the sources of those causes.

- EPA uses this approach to highlight many of the fundamental conceptual issues that must be addressed if the Nation is to learn about current water quality conditions and trends.

- Finally, the 1994 report does not stand alone. Previous reports — although based on different data sets, methodologies, criteria, and standards — have reached the same conclusion: Chemicals and sediments associated with agricultural production are major causes and sources of surface water impairments in assessed water bodies.

Water quality—the 1994 305(b) Report

Individual States report that 17 percent of United States (including Puerto Rico and tribal lands) rivers and streams, 42 percent of lakes, reservoirs, and ponds, and 78 percent of estuarine waters were assessed in 1992-1993. Figure 4-1 shows a wide variation in the degree of reporting among NRCS regions: from 63 percent of rivers and streams in the East to 5 percent in the West; from 11 percent of lakes in the West to 84 percent in both the Northern Plains and East; and from 28 percent of estuarine waters in the West to 95 percent in the East. The figure also shows that, in terms of water body areas, the percentage assessed was greater for estuaries than for lakes, and greater for lakes than for rivers, both nationally and in each NRCS region.

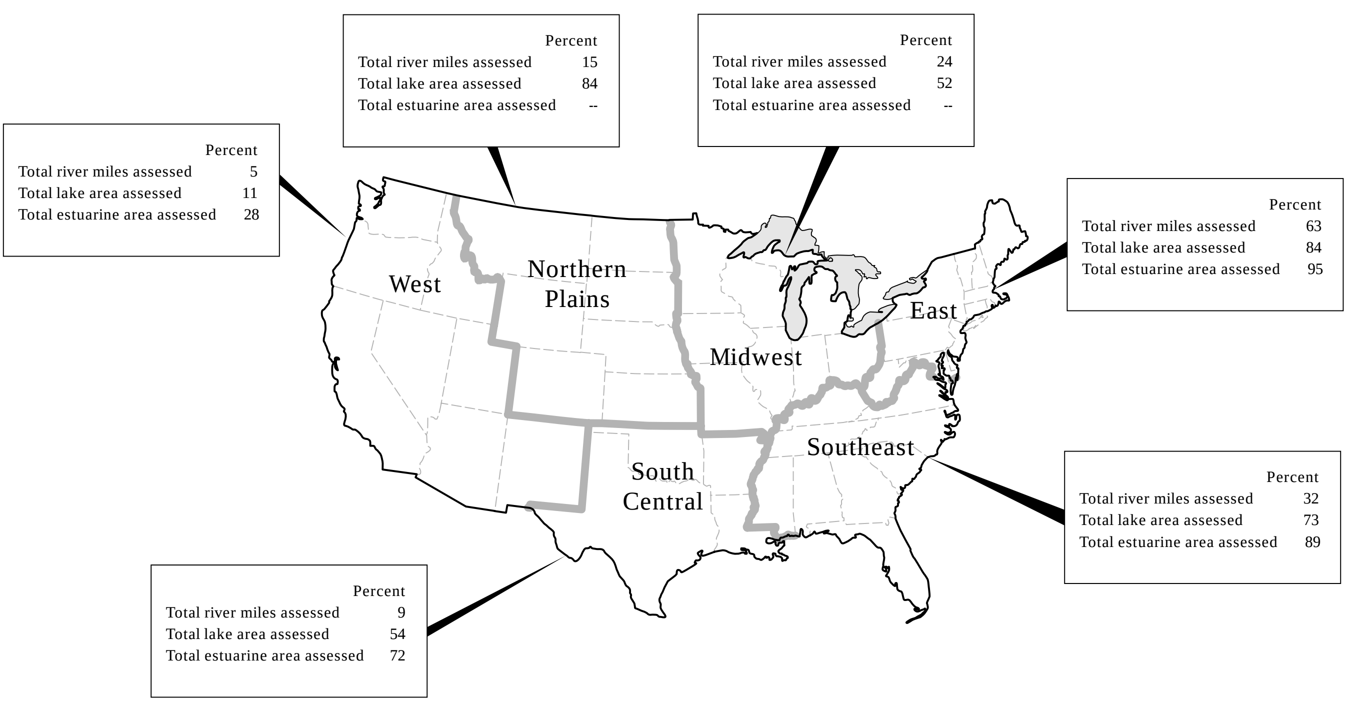
Impairment sources

Nationally, agriculture was by far the leading source of pollution of assessed rivers and lakes (see table 4-1). However, the combination of municipal, industrial, and urban point and nonpoint sources was equally as important a polluter as agriculture was for lakes. This combination was also the largest source of pollution to the Nation's estuaries.

Table 4-2 compares regional impairments, in terms of the percentage of waters assessed, from agricultural sources alone to impairments from all sources. It does not have any information about waters not assessed in the 1992-1993 reporting cycle to EPA. The conditions of these waters could be better, the same as, or worse than conditions in the assessed water. For the waters assessed:

- agricultural sources impair rivers proportionately less in the East region (five percent of rivers assessed) and the Southeast (15 percent) and more in the Northern Plains (44 percent) and West (36 percent). Nationally, agriculture is cited as an impairment source for 22 percent of these miles.
- agriculture is more evenly cited as an impairment source across NRCS regions for lakes than for rivers. It is reported for 21-28 percent of lake area in four regions. It is of least importance to the Midwest and South Central lakes.
- Of the four regions reporting estuary pollution, agriculture is most often cited as a source in the Southeast and East at 30-35 percent of assessed area.

Figure 4-1 Percent of rivers and streams; lakes, reservoirs, and ponds; and estuarine waters assessed, by NRCS Region, 1992 and 1993 (derived from U.S. EPA, 1995)



U.S. Total

	Percent
Total river miles assessed	17
Total lake area assessed	42
Total estuarine area assessed	78

This figure has no information on water not reported to EPA. Impairments in that water could be worse, the same as, or better than in impaired water.

Table 4-1 Leading sources of pollution of assessed waters in the U.S., 1992 and 1993 (derived from U.S. EPA, 1995) [a]

SOURCES	Rivers & Streams	Rank	Lakes & Reservoirs	Rank	Estuaries	Rank
	(1000 miles) [a]		(1000 acres) [b]		(sq mi) [c]	
Agriculture	135	(1)	3,350	(1)	3,321	(3)
Hydro/habitat changes	37	(4)	[d]		[d]	
Municipal/industrial point sources	53	(2)	2,025	(2)	6,436	(1)
Natural	42	(3)	965	(5)	2,949	(4)
Unspecified nonpoint sources	[d]		989	(4)	991	(5)
Urban runoff/storm sewers	27	(5)	1,200	(3)	4,508	(2)

Note:

Multiple sources were reported for the same water body areas. The table includes Puerto Rico and tribal lands. It does not include the Pacific Basin or the Virgin Islands for lack of data. Not all water is assesed by the States in each reporting cycle to the EPA.

[a] Total river and stream mileage is 3.5 million miles.
[b] Total lake, reservoir, and pond area is 40.8 million acres.
[c] Total estuarine water area is 34.4 thousand square miles.
[d] Not among the top 5 sources.

Table 4-2 Comparison of use impairments from all sources and from agriculture as a percentage of waters assessed, by NRCS Region, 1992 and 1993 (derived from U.S. EPA, 1995)

Region	Rivers & Streams		Lakes & Reservoirs		Estuaries	
	All sources	Agriculture only	All sources	Agriculture only	All sources	Agriculture only
	Impairment for one or more uses as a percentage of assessed area					
U.S.	36	22	39	20	36	12
East	14	5	41	27	53	30
Southeast	33	15	35	21	24	35
Midwest	34	24	25	8	NA	NA
South Central	51	30	29	14	31	0
Northern Plains	52	44	62	28	NA	NA
West	65	36	54	26	73	13

Note:

Multiple causes were reported for the same water body areas. The table includes Puerto Rico and tribal lands. It does not include the Pacific Basin or the Virgin Islands for lack of data. Not all water is assessed by the States in each reporting cycle to EPA. Impairments to unassessed waters are not known.

Impairment causes: rivers and streams

Because water can be affected by multiple pollutants, States may properly report a stream mile or lake acre several times. At the national level, causes for assessed river impairment from all sources including agricultural sources were as follows:

	(miles)
siltation*	75,792
bacteria and pathogens *	76,397
nutrients *	50,923
oxygen depletors	41,374
metals	38,552
habitat alteration	34,878
suspended solids *	30,927
flow alteration	25,240
salinity/TDS/chlorides *	24,283
pesticides *	24,118

Causes marked with an " * " are often associated with agriculture but they may come from other sources. A brief discussion of "siltation" and "bacteria and pathogens" illustrates this point. Siltation is used to describe the suspension and deposition of small "sediment" particles in water bodies. Sediment usually refers to soil particles that enter the water column from eroding land. Rain washes silt off of farm fields, construction sites, urban areas, etc. Bacteria and pathogens may enter waters through a number of routes including inadequately treated sewage, stormwater drains, runoff from livestock, and other sources. Because it is impossible to test waters for every possible disease-causing organism, States usually measure indicator bacteria that are found in the stomachs and intestines of warm-blooded animals and people.

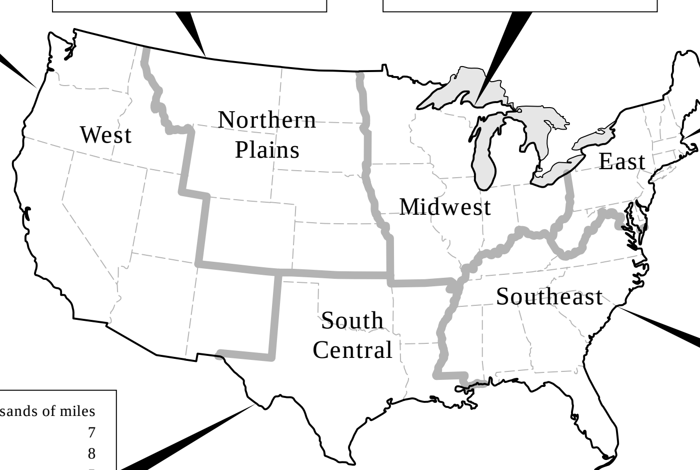
Figure 4-2 Assessed river miles reported impaired from all sources, by cause of impairment and NRCS Region, 1992 and 1993 (derived from U.S. EPA, 1995)

	Thousands of miles
Siltation	13
Bacteria, pathogens	22
Nutrients	9
Pesticides	6
Suspended solids	20
Salinity/TDS/chlorides	17

	Thousands of miles
Siltation	23
Bacteria, pathogens	9
Nutrients	11
Pesticides	2
Suspended solids	1
Salinity/TDS/chlorides	1

	Thousands of miles
Siltation	9
Bacteria, pathogens	8
Nutrients	6
Pesticides	3
Suspended solids	1
Salinity/TDS/chlorides	3

	Thousands of miles
Siltation	9
Bacteria, pathogens	7
Nutrients	7
Pesticides	1
Suspended solids	2
Salinity/TDS/chlorides	1



	Thousands of miles
Siltation	16
Bacteria, pathogens	23
Nutrients	13
Pesticides	8
Suspended solids	3
Salinity/TDS/chlorides	1

	Thousands of miles
Siltation	7
Bacteria, pathogens	8
Nutrients	5
Pesticides	4
Suspended solids	4
Salinity/TDS/chlorides	2

U.S. miles reported impaired

	Thousands of miles
Siltation	76
Bacteria, pathogens	76
Nutrients	51
Pesticides	24
Suspended solids	31
Salinity/TDS/chlorides	24

This figure has no information on water not reported to EPA. Impairments in that water could be worse, the same as, or better than in impaired water.

In terms of assessed river miles impaired, two of the top three causes—siltation and nutrients—are most often found in the Midwest (23,000 miles and 11,000 miles, respectively) and Southeast (16,000 miles and 13,000 miles, respectively). See Figure 4-2 and Table 4-3. The other top cause—bacteria and pathogens—is most often found in the Northern Plains (22,000 miles) and the Southeast (23,000 miles). Miles impaired by suspended solids and salinity/TDS/chlorides are much lower nationally than these other causes but they are concentrated in one region, the Northern Plains (20,000 miles and 17,000 miles, respectively).

Because the number of river miles assessed varies by region, Figure 4-3 provides a slightly different regional picture by showing the *percentage* of assessed miles impaired by each cause. Siltation, bacteria, and nutrients are still the top three national causes. Of most interest regionally is that for these three pollutants and for pesticides, the South Central becomes the first or second region in reporting these causes as a percentage of area assessed and the Southeast drops in reporting frequency.

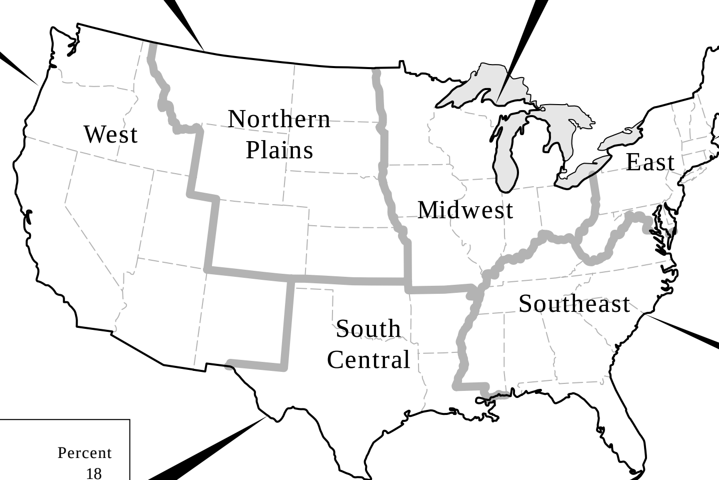
Figure 4-3 Assessed river miles impaired from all sources as a percentage of miles reported, by cause of impairment and NRCS Region, 1992 and 1993 (derived from U.S. EPA, 1995)

	Percent
Siltation	14*
Bacteria, pathogens	23*
Nutrients	9*
Pesticides	6*
Suspended solids	21
Salinity/TDS/chlorides	18*

	Percent
Siltation	22
Bacteria, pathogens	9
Nutrients	11*
Pesticides	2*
Suspended solids	1
Salinity/TDS/chlorides	1*

	Percent
Siltation	13
Bacteria, pathogens	12*
Nutrients	8
Pesticides	4*
Suspended solids	2*
Salinity/TDS/chlorides	4

	Percent
Siltation	6
Bacteria, pathogens	5
Nutrients	5
Pesticides	4*
Suspended solids	1*
Salinity/TDS/chlorides	--*



	Percent
Siltation	10
Bacteria, pathogens	14
Nutrients	8*
Pesticides	5*
Suspended solids	2*
Salinity/TDS/chlorides	--*

	Percent
Siltation	18
Bacteria, pathogens	20
Nutrients	14*
Pesticides	11*
Suspended solids	10*
Salinity/TDS/chlorides	6*

U.S. Total

	Percent
Siltation	16
Bacteria, pathogens	16
Nutrients	11
Pesticides	5
Suspended solids	6
Salinity/TDS/chlorides	5

— = less than 1 percent
* = 1 state accounts for ≥ 50 % of impairment

This figure has no information on water not reported to EPA. Impairments in that water could be worse, the same as, or better than in impaired water.

Table 4-3 Causes of impairment in assessed rivers and streams from all sources, by cause and NRCS Region, 1992 and 1993 (derived from U.S. EPA, 1995)

Region	Total miles	Siltation	Bacteria/ pathogens	Nutrients	Pesticides	Suspended solids	Salinity/ TDS/ chlorides
	Assessed	Total miles impaired					
East							
Total assessed (mi)	141,990	8,548	6,926	7,445	1,453	1,902	651
Impaired/assessed (%)		6	5	5	1	1	*
Top State: impaired/assessed (%)		43	22	40	72	57	85
Southeast							
Total assessed (mi)	167,573	16,083	23,291	12,806	7,870	2,993	507
Impaired/assessed (%)		10	14	8	5	2	*
Top State: impaired/assessed (%)		39	40	55	82	58	54
Midwest							
Total assessed (mi)	102,818	22,799	8,883	10,826	1,816	1,217	835
Impaired/assessed (%)		22	9	11	2	1	1
Top State: impaired/assessed (%)		26	49	63	75	20	61
South Central							
Total assessed (mi)	37,832	6,708	7,571	5,141	4,147	3,927	2,206
Impaired/assessed (%)		18	20	14	11	10	6
Top State: impaired/assessed (%)		45	49	52	70	59	59
Northern Plains							
Total assessed (mi)	94,983	12,828	21,508	8,824	5,796	19,543	16,990
Impaired/assessed (%)		14	23	9	6	21	18
Top State: impaired/assessed (%)		54	76	70	85	49	55
West							
Total assessed (mi)	69,387	8,825	8,217	5,881	3,036	1,345	3,094
Impaired/assessed (%)		13	12	8	4	2	4
Top State: impaired/assessed (%)		44	53	42	81	86	38
U.S.							
Total assessed (mi)	478,963	75,792	76,397	50,923	24,117	30,927	24,283
Impaired/assessed (%)		16	16	11	5	6	5

Note: This table presents only those causes of water impairment that are most often associated with agriculture. It does not include the Virgin Islands or Pacific Basin for lack of data. Not all water is assessed by the States for each EPA reporting cycle. Impairments to unassessed water are not known.

“ *” = Impaired is less than 0.5 % of total assessed area.

Impairment causes: lakes, reservoirs, and ponds

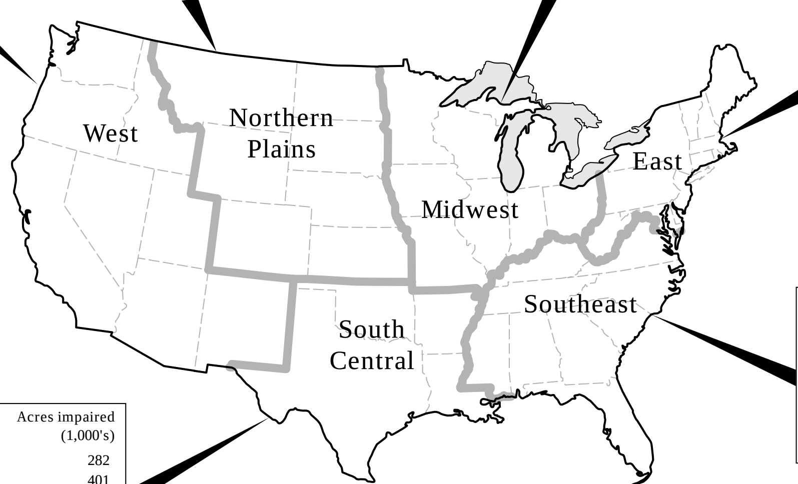
The order of impairment causes often associated with agriculture, but coming from all sources including agriculture, differs materially from that seen for rivers and streams. In terms of lake, reservoir, and pond acres impaired, the causes are:

	(acres)
nutrients *	2,848,073
siltation*	1,855,923
oxygen depletors	1,597,071
metals	1,431,956
suspended solids*	932,212
pesticides *	759,565
toxic organics	527,425
algae	468,075
salinity/TDS/chlorides *	464,062
bacteria/pathogens *	456,486

Causes marked with an " * "are often associated with agriculture, but may come from other sources also. Nutrients are first among causes of impaired lake acres; they were the third cause for rivers. Siltation is second and no longer first; bacteria/pathogens are tenth and not second; suspended solids are fifth and not seventh; and pesticides are sixth and not tenth.

In terms of numbers of assessed lake acres impaired, two of the top three causes often associated with agriculture— nutrients and suspended solids—are most often found in the Northern Plains (810,000 acres and 359,000 acres). See Figure 4-4 and Table 4-4. The West reported the most acres for the other top cause—siltation (480,000 acres)—as well as the most for salinity (261,000 acres). Pesticides and bacteria/ pathogens are most reported in the South Central and the East.

Figure 4-4 Assessed lakes, reservoirs, and ponds reported impaired from all sources, by cause of impairment and NRCS Region, 1992 and 1993 (derived from U.S. EPA, 1995)



West

Acres impaired (1,000's)	
Nutrients	562
Siltation	480
Suspended solids	99
Pesticides	54
Bacteria, pathogens	51
Salinity/TDS/chlorides	261

Northern Plains

Acres impaired (1,000's)	
Nutrients	810
Siltation	329
Suspended solids	359
Pesticides	110
Bacteria, pathogens	64
Salinity/TDS/chlorides	57

Midwest

Acres impaired (1,000's)	
Nutrients	293
Siltation	192
Suspended solids	130
Pesticides	27
Bacteria, pathogens	6
Salinity/TDS/chlorides	—

East

Acres impaired (1,000's)	
Nutrients	590
Siltation	296
Suspended solids	1
Pesticides	203
Bacteria, pathogens	211
Salinity/TDS/chlorides	75

Southeast

Acres impaired (1,000's)	
Nutrients	311
Siltation	158
Suspended solids	88
Pesticides	146
Bacteria, pathogens	80
Salinity/TDS/chlorides	1

South Central

Acres impaired (1,000's)	
Nutrients	282
Siltation	401
Suspended solids	255
Pesticides	218
Bacteria, pathogens	44
Salinity/TDS/chlorides	69

U.S. Total

Acres impaired (1,000's)	
Nutrients	2848
Siltation	1856
Suspended solids	932
Pesticides	760
Bacteria, pathogens	456
Salinity/TDS/chlorides	464

— = less than 1 percent

This figure has no information on water not reported to EPA. Impairments in that water could be worse, the same as, or better than in impaired water.

Table 4-4 Causes of impairment in assessed lakes, reservoirs, and ponds from all sources, by cause and NRCS Region, 1992 and 1993 (derived from U.S. EPA, 1995)

REGION	Total acres (1000's)	Nutrients	Siltation	Suspended solids	Pesticide	Bacteria	Salinity TDS Chlorides
	Assessed	Total acres (1000's) impaired					
EAST							
Total assessed	2,266	590	296	0.6	203	211	75
Impaired/assessed (%)		26	13	*	9	9	3
Top State: impaired/assessed (%)		52	73	17	100	98	95
Southeast							
Total assessed	3,861	311	158	88	146	80	1
Impaired/assessed (%)		8	4	2	4	2	—
Top State: impaired/assessed (%)		42	72	76	77	32	89
Midwest							
Total assessed	3,253	293	192	130	27	6	*
Impaired/assessed (%)		9	6	4	1	*	*
Top State: impaired/assessed (%)		43	66	97	50	54	*
South Central							
Total assessed	3,069	282	401	255	218	44	69
Impaired/assessed (%)		9	13	8	7	1	2
Top State: impaired/assessed (%)		91	97	99	99	82	100
Northern Plains							
Total assessed	2,683	810	329	359	110	64	57
Impaired/assessed (%)		30	12	13	4	2	2
Top State: impaired/assessed (%)		55	38	86	96	60	47
West							
Total assessed	2,001	562	480	99	54	51	261
Impaired/assessed (%)		28	24	5	3	3	13
Top State: impaired/assessed (%)		30	69	99	97	54	46
United States							
Total assessed	1,713	2,848	1,856	932	760	456	464
Impaired/assessed (%)		17	11	5	4	3	3

Note: This table presents only those causes of water impairment that are most often associated with agriculture. It does not include the Virgin Islands or Pacific Basin for lack of data. Not all water is assessed by the States for each EPA reporting cycle. Impairments to unassessed water are not known.

"*" = Impaired is less than 0.5 % of total assessed area

Because the number of lake acres assessed varies by region, Figure 4-5 provides a slightly different regional picture by showing the *percentage* of assessed acres impaired by each cause. Nutrients, siltation, and suspended solids are still the top three national causes. Shifting to a percentage of acres reported basis has the effect of grouping two additional regions—the West and East—with the Northern Plains as the regions finding nutrients impairing the largest percentage of lake acres (ranging from 26% to 30%).

Impairment causes: estuaries

Nutrients and bacteria and pathogens from all sources are again leading national causes of impairment when measured on an area basis. In contrast to the situation for rivers and lakes, siltation is reported to be much less important as a pollution cause. Suspended solids and salinity have a relatively higher cause ranking than for rivers and lakes.

	(square miles)
nutrients *	4,548
bacteria and pathogens *	4,479
suspended solids *	895
salinity/TDS/chlorides *	851
oil and grease	673
siltation *	555
pesticides *	412
pH	269

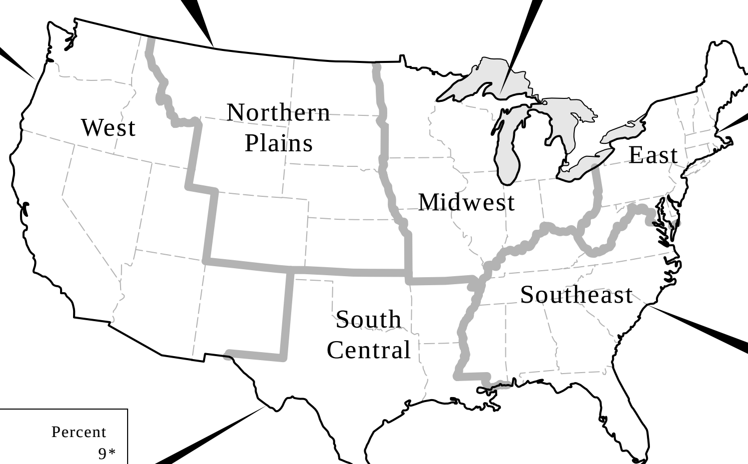
Figure 4-5 Assessed lakes, reservoirs, and ponds reported impaired from all sources, as a percentage of assessed area, by cause of impairment and NRCS Region, 1992 and 1993 (derived from U.S. EPS, 1995)

	Percent
Nutrients	30 *
Siltation	12
Suspended solids	13 *
Pesticides	4 *
Salinity/TDS/chlorides	2
Bacteria, pathogens	2 *

	Percent
Nutrients	9
Siltation	16 *
Suspended solids	4 *
Pesticides	1 *
Salinity/TDS/chlorides	-- *
Bacteria, pathogens	-- *

	Percent
Nutrients	28
Siltation	24 *
Suspended solids	5 *
Pesticides	3 *
Salinity/TDS/chlorides	13
Bacteria, pathogens	3 *

	Percent
Nutrients	26 *
Siltation	13 *
Suspended solids	--
Pesticides	9 *
Salinity/TDS/chlorides	3 *
Bacteria, pathogens	9 *



	Percent
Nutrients	8
Siltation	4
Suspended solids	2 *
Pesticides	4 *
Salinity/TDS/chlorides	-- *
Bacteria, pathogens	2 *

	Percent
Nutrients	9 *
Siltation	13 *
Suspended solids	8 *
Pesticides	7 *
Salinity/TDS/chlorides	2 *
Bacteria, pathogens	1 *

U.S. Total

	Percent
Nutrients	17
Siltation	11
Suspended solids	5
Pesticides	4
Salinity/TDS/chlorides	3
Bacteria, pathogens	3

— = less than 1 percent
* = 1 state accounts for ≥ 50 % of impairmant

This figure has no information on water not reported to EPA. Impairments in that water could be worse, the same as, or better than in impaired water.

Whether impairment is considered in terms of total area impaired or as a percent of just the assessed area, the East region most often found (in 2,931 square miles) nutrients as cause of estuarine impairment. See Figure 4-6 and Table 4-5. The South Central, and then the East, reported the greatest number of square miles impaired by bacteria and pathogens, 1,836 and 1,403 square miles, respectively. But on a percentage of reported area impaired by bacteria, the West which reported a much smaller estuarine area than the other regions, reported the largest percentage (38 %) impaired by this cause. See Figure 4-7.

Figure 4-6 Assessed estuaries reported impaired from all sources, by cause of impairment and NRCS Region, 1992 and 1993 (derived from U.S. EPA, 1995)

West

	Square miles
Nutrients	83
Bacteria, pathogens	446
Siltation	39
Suspended solids	16
Pesticides	296
Salinity/TDS/chlorides	0

East

	Square miles
Nutrients	2,931
Bacteria, pathogens	1,403
Siltation	508
Suspended solids	406
Pesticides	116
Salinity/TDS/chlorides	0

Southeast

	Square miles
Nutrients	247
Bacteria, pathogens	795
Siltation	9
Suspended solids	472
Pesticides	0
Salinity/TDS/chlorides	0

South Central

	Square miles
Nutrients	1,286
Bacteria, pathogens	1,836
Siltation	0
Suspended solids	0
Pesticides	0
Salinity/TDS/chlorides	851

U.S.Area Impaired

	Square miles
Nutrients	4,548
Bacteria, pathogens	4,479
Siltation	555
Suspended solids	879
Pesticides	411
Salinity/TDS/chlorides	851

This figure has no information on water not reported to EPA. Impairments in that water could be worse, the same as, or better than in impaired water.

Table 4-5 Causes of impairment in assessed estuaries from all sources, by cause and NRCS Region, 1992 and 1993 (derived from U.S. EPA, 1995)

Region	Total square miles	Nutrients	Bacteria	Siltation	Suspended solids	Pesticides	Salinity TDS Chlorides
	Assessed	Total square miles impaired					
EAST							
Total assessed	7,591	2,931	1,403	508	406	116	0
Impaired/assessed (%)		39	18	7	5	2	*
Top State: impaired/ (%) assessed		83	29	67	97	60	100
SOUTHEAST							
Total assessed	11,134	247	795	9	472	0	0
Impaired/assessed (%)		2	7	*	4	*	*
Top State: impaired/ (%) assessed		99	50	81	100	*	*
SOUTH CENTRAL							
Total assessed	6,932	1,286	1,836	0	0	0	851
Impaired/assessed (%)		19	26	*	*	*	12
Top State: impaired/ (%) assessed		100	59	*	*	*	100
WEST							
Total assessed	1,189	83	446	39	16	296	0
Impaired/assessed (%)		7	38	3	1	25	*
Top State: impaired/ (%) assessed		69	64	68	100	99	100
U.S.							
Total assessed	26,847	4,548	4,479	555	879	412	851
Impaired/ (%) assessed		17	17	2	3	2	3

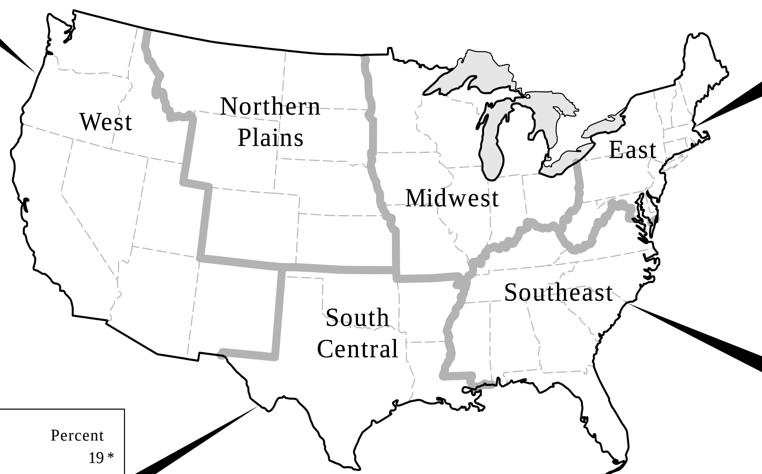
Note: This table presents only those causes of water impairment that are most often associated with agriculture. It does not include the Virgin Islands or Pacific Basin for lack of data. Not all water is assessed by the States for each EPA reporting cycle. Impairments to unassessed water are not known.

“ * ” = Impaired is less than 0.5 % of total assessed area.

Figure 4-7 Assessed estuaries reported impaired from all sources as a percentage of area assessed, by cause of impairment and NRCS Region, 1992 and 1993 (derived from U.S. EPA, 1995)

West

	Percent
Nutrients	7 *
Bacteria, pathogens	38 *
Siltation	3 *
Suspended solids	1 *
Pesticides	25 *
Salinity/TDS/chlorides	— *



East

	Percent
Nutrients	39*
Bacteria, pathogens	18
Siltation	7*
Suspended solids	5*
Pesticides	2*
Salinity/TDS/chlorides	—*

Southeast

	Percent
Nutrients	2*
Bacteria, pathogens	7*
Siltation	—*
Suspended solids	4*
Pesticides	—
Salinity/TDS/chlorides	—

South Central

	Percent
Nutrients	19 *
Bacteria, pathogens	26 *
Siltation	—
Suspended solids	—
Pesticides	—
Salinity/TDS/chlorides	12 *

United States Area Impaired / United States Area Assessed

	Percent
Nutrients	17
Bacteria, pathogens	17
Siltation	2
Suspended solids	3
Pesticides	2
Salinity/TDS/chlorides	3

— = less than 1%
* = 1 state accounts for ≥ 50% impairment

This figure has no information on water not reported to EPA. Impairments in that water could be worse, the same as, or better than in impaired water.

Chapter 5 Measured Water Quality Status and Trends

Surface water quality

The range of indicators that describe different aspects of stream water quality in existing national databases is severely limited. Smith, Alexander, and Lanfear (1993) chose to analyze dissolved oxygen, fecal coliform bacteria, dissolved solids, dissolved nitrite plus nitrate (referred to as nitrate and expressed as nitrate nitrogen), total phosphorus, and suspended sediment in 1,400 monitoring stations from 1980 through 1989, except 1982 to 1989 for phosphorus. Depending on the indicator, the number of stations meeting their selection criteria ranged from 313 to 424. The surface water quality material in this chapter draws heavily on their report, which presented monitored values for each water quality indicator by major land use. Their land use classification is based on land cover characteristics, crop type, population density, and total surface and ground water withdrawals for domestic use (fig. 5–1).

Rivers and streams

Dissolved oxygen

Dissolved oxygen (DO) is essential to the respiration of aquatic organisms. Its concentration in streams is a major determinant of the species composition of aquatic biota and underlying sediments. The DO concentration in stream water ranges from about 14 mg/L at freezing to about 7 mg/L at 86˚F. In ecologically healthy streams, the DO concentration depends primarily on temperature, which varies with season and climate. Studies (U.S. Environ. Prot. Agency, 1986) suggest that streams with concentrations below 6.5 mg/L for more than about 20 percent of the time are not capable of supporting trout or other cold-water fish.

Figure 5–2 shows average concentration of DO and the percentage of samples (frequency of occurrence) of concentrations less than 6.5 mg/L at each of 424 selected stations. The figure shows a climate-related pattern of decreasing average DO concentration from north to south. Among the four land uses, average concentrations were the lowest in urban areas (fig. 5–2B).

Figure 5–2C shows that upward trends in DO concentration outnumbered downward trends, especially in the central States. In general, increases in DO represent an improvement in water quality. Nationally, the percentage of stations having more than 20 percent of concentrations less than 6.5 mg/L remained nearly constant at 20 percent (fig. 5–2D).

Changes in DO concentrations in streams during the 1980s are particularly important, given the large capital investment made to control point-source pollution. Between 1980 and 1989, municipalities spent some $126 billion to upgrade treatment facilities, and private industry spent $68 billion to reduce point-source biochemical oxygen demand loads (U.S. Environ. Prot. Agency, 1990a).

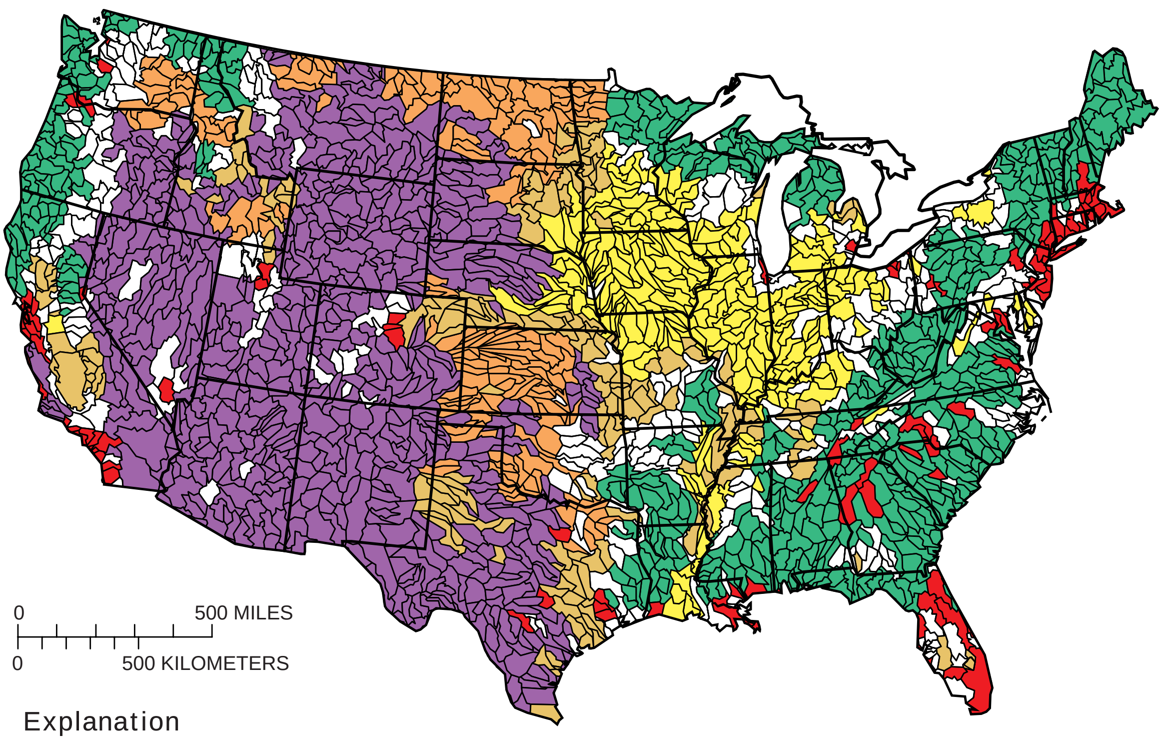
Nationally, however, the lack of change in DO concentration could reflect that the investment in point-source pollution controls has simply kept pace with population increases and economic development. Oxygen-demanding waste loads declined substantially in the 1970s but were nearly stable during the 1980s (U.S. Environ. Prot. Agency, 1990a). Despite point-source control expenditures, the loads did not decline in the 1980s because the population increased by 10 percent and the real gross national product increased by 30 percent (U.S. Bur. Census, 1990). Maintaining nearly constant DO concentration in streams during this period of increased pollution generation represents an important environmental benefit of pollution controls.

Fecal coliform bacteria

Concentration of fecal coliform bacteria is a reliable indicator of fecal contamination from warm-blooded animals (U.S. Environ. Prot. Agency, 1976). Fecal material in water where humans swim or where shellfish are harvested presents a significant risk of infection from pathogenic organisms. The major sources are untreated sewage, effluent from sewage treatment plants, and runoff from pastures, feedlots, and urban areas.

A concentration of 200 bacterial colonies per 100 milliliters (mL) of water has long been considered the acceptable limit for fecal coliform density in waters with human contact (U.S. Environ. Prot. Agency, 1976). An arbitrary threshold of 1,000 bacterial colonies per 100 mL categorizes high concentrations. Figure 5–3A indicates widespread and frequent bacterial concentrations greater than the acceptable limit during the 1980s, but gradual progress made in reduc-

Figure 5-1 Land-use classification (Smith et al. 1993). This classification was derived as follows: agriculture land use by type of land and the crops grown; urban use by type of land cover, population density, and total surface and ground water withdrawals for domestic use; forest and range land use by type of land cover. For the range land use, the aggregate land-cover percentages for agriculture, forest and urban cannot exceed 50 percent (>, greater than; <, less than)



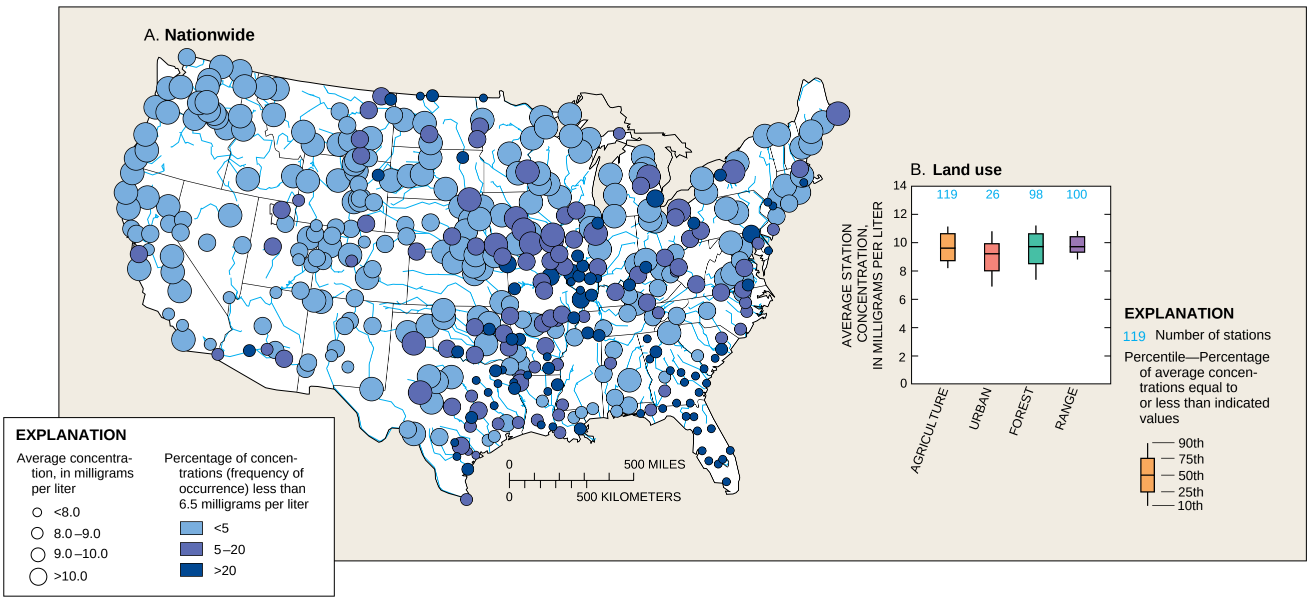
Explanation

Boundary of hydrologic cataloging unit

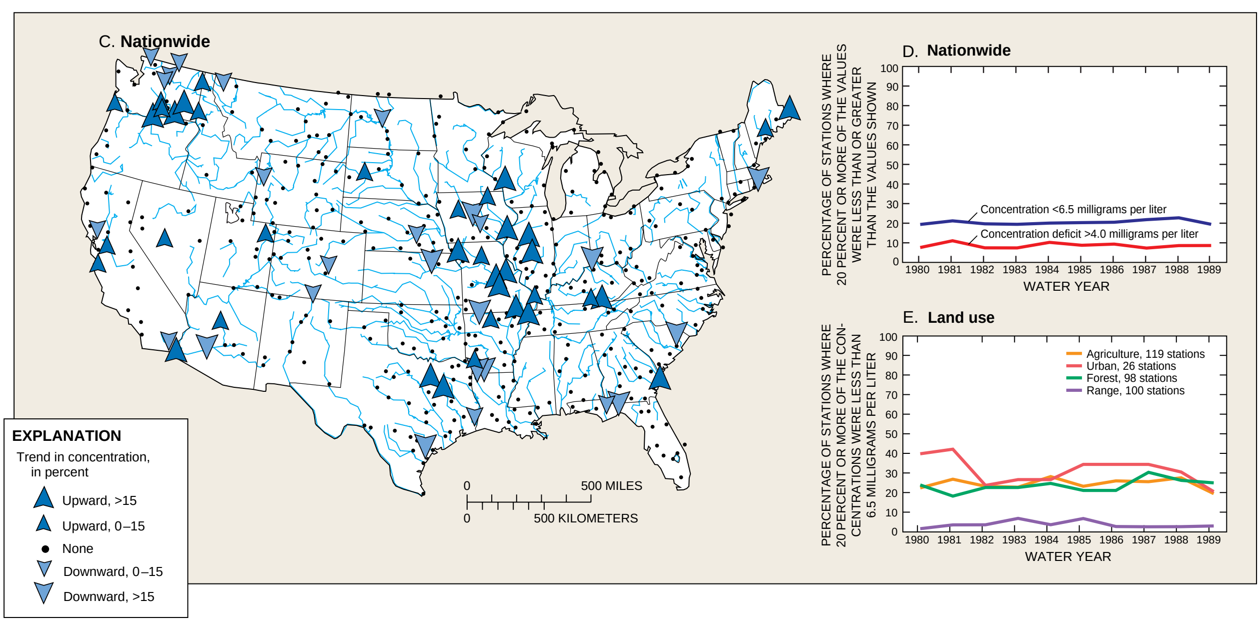
LAND USE SHOWN ON MAP	CRITERIA FOR DETERMINING LAND USE (Land cover, in percent; crop type, in percent; population density, in persons per square mile; total water withdrawals for domestic use, in million gallons per day)	
AGRICULTURE Wheat	Land Cover: > 40 crop and pasture < 40 forest < 10 urban	Crop type: > 50 wheat < 20 corn and soybeans
Corn and soybeans	Land Cover: > 40 crop and pasture < 40 forest < 10 urban	Crop type: > 50 corn and soybeans < 20 wheat
Mixed	Land Cover: > 40 crop and pasture < 40 forest < 10 urban	Crop type: < 50 wheat, corn and soybeans
URBAN	Land Cover: < 30 forest Population: > 100	Total water withdrawals for domestic use: > 6
FOREST	Land Cover: > 50 forest < 40 agriculture < 10 urban	
RANGE	Land Cover: > 50 range and barren land < 40 agriculture	< 40 forest <10 urban
OTHER	All land cover not meeting any of the above criteria	

Figure 5-2 Concentration and trends in dissolved oxygen in stream water, 1980 to 1989 (Smith et al. 1993)

Average concentration



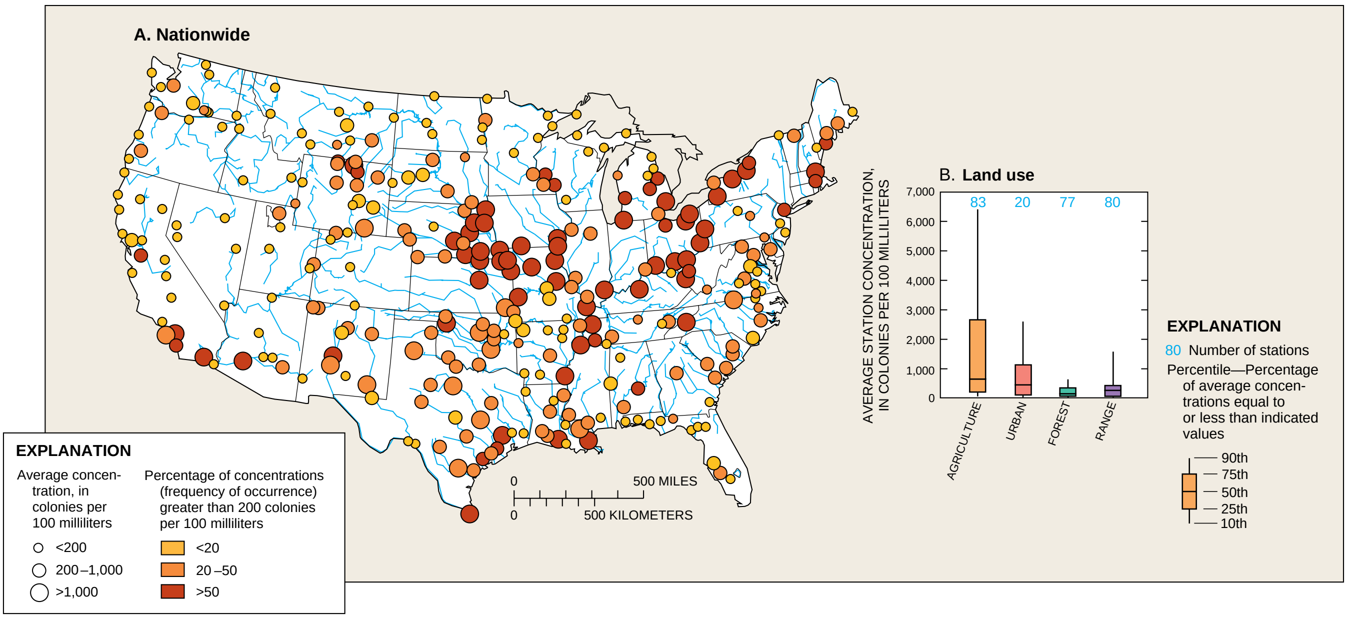
Trends in concentration



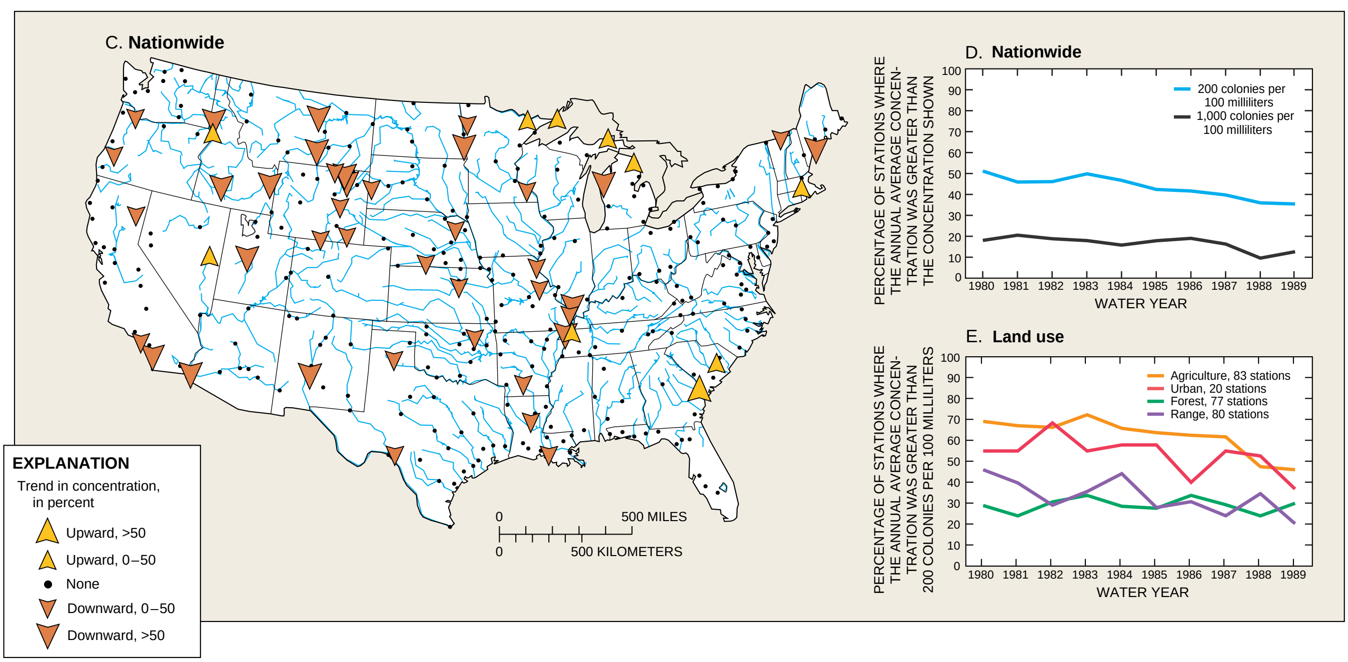
Concentration and trends in dissolved oxygen in stream water at 424 selected water-quality monitoring stations in the conterminous United States, water years 1980-89. A: Average concentration and percentage of concentrations less than 6.5 mg/L nationwide. B: Average concentration, by land use. C: Trends in concentration nationwide. D: Percentage of stations nationwide were 20 percent or more of the dissolved-oxygen concentrations were less than 6.5 mg/L, E: Percentage of stations where 20 percent or more of the dissolved-oxygen concentrations were less than 6.5 mg/L, by land use (> greater than; < less than).

Figure 5-3 Concentration and trends in fecal coliform bacteria in stream water, 1980 to 1989 (Smith et al. 1993)

Average concentration



Trends in concentration



Concentration and trends in fecal coliform bacteria in stream water at 313 selected water-quality monitoring stations in the conterminous United States, water years 1980-89. A: Average concentration and percentage of concentrations greater than 200 colonies per 100 milliliters nationwide. B: Average concentration, by land use. C: Trends in concentration nationwide. D: Percentage of stations nationwide where the annual average concentration was greater than 200 or 1,000 colonies per millileter. E: Percentage of stations where the annual average concentration was greater than 200 or 1,000 colonies per millili-ter, by land use (> greater than; < less than).

ing concentrations. Concentrations over the acceptable limit occurred in at least 20 percent of the samples at a significant majority of the 313 stations sampled. Concentrations were highest in the midwestern and south-central agricultural areas and in several tributaries to the eastern Great Lakes. At many stations in agricultural areas, average bacterial concentrations were greater than 1,000 colonies per 100 mL.

Downward trends (fig. 5–3C) occurred at 40 stations, and upward trends at 10 stations. Concentration decreases were especially common in the central United States, occurring in areas with significant urban, agricultural, or range land use. The percentage of stations nationwide where the annual average concentration was greater than 1,000 colonies per 100 mL decreased from 18 to 13 percent. The percentage of stations with annual average concentrations greater than the acceptable limit of 200 colonies per 100 mL decreased from 52 to 35 percent (fig. 5–3D). In all land use areas except forested areas, the percentage of stations in which annual average concentration was greater than 200 colonies per 100 mL decreased. All trends suggest that control of point and nonpoint sources of fecal coliform bacteria improved over the decade.

Dissolved solids

Dissolved solids come from minerals naturally found in soil and rock, such as ions of calcium, magnesium, sodium, potassium, biocarbonate, sulfate, and chloride. The major significance of dissolved solids is the potential limitation that large concentrations impose on certain domestic, industrial, and irrigation water uses. The highest concentrations (greater than 500 mg/L) are found in the arid Southwest, where high rates of evaporation and transpiration tend to concentrate dissolved solids. Concentrations are lowest (less than 100 mg/L) in the eastern and northwestern United States, where high precipitation rates dilute dissolved constituents.

During the 1980s, trends varied nationwide. Out of 340 stations, downward trends at 46 stations outnumbered upward trends at 28 stations. Downward trends were especially common in the central United States, the Pacific Northwest, and the far Southwest; upward trends were most common in drainage to the Gulf of Mexico and the Atlantic Ocean.

Nitrate

High nitrate concentrations in streams can have serious toxicological and ecological effects. The EPA standard for nitrate-N in drinking water is 10 mg/L.

Nitrate concentrations rarely exceed 10 mg/L in streams, but they frequently exceed the limit in shallow ground water in agricultural areas where animal wastes and nitrogen fertilizers are concentrated. Smith et al. (1993) arbitrarily used three nitrate concentrations for their analysis of surface water: less than 1 mg/L, 1 to 3 mg/L, and greater than 3 mg/L.

Ecological concern about high nitrate concentrations in streams (see chapter 2) also involves nitrate's potential contribution to eutrophication. No nationally applicable threshold concentration for nitrate exists to protect against eutrophication.

Figure 5–4A shows that average nitrate concentrations were greater than 3 mg/L at several midwestern and southwestern stations. In most other areas, concentrations averaged less than 1 mg/L. At stations in agricultural and urban areas, average concentrations were much greater than those in forested and range areas (fig. 5–4B).

Among 344 stations, significant trends in concentration (fig. 5–4C) were nearly equally divided between upward trends in 22 stations and downward trends in 27 stations. Downward trends occurred predominantly in the eastern, south-central, and southeastern United States; whereas upward trends were geographically scattered. Nationally, the percentage of stations having average concentrations greater than 1 mg/L remained constant at about 20 percent (fig. 5–4D). Some evidence suggests success in reducing nitrate levels in streams with high concentrations; the percentage of stations nationwide with annual average concentrations greater than 3 mg/L decreased from about 6.5 to 4 percent. In agricultural areas, the percentage of stations where the annual average concentration was greater than 1 mg/L reached a peak at 46 percent in 1984 and then declined to 34 percent by 1989 (fig. 5–4E).

These 1980 to 1989 trends are a noteworthy change from 1974 to 1981, when increases in nitrate were widespread and appeared related to large increases in nitrogen fertilizer use through 1981 (Smith et al. 1987).

The lack of a nationwide trend in nitrate concentration in streams during the 1980s, therefore, is consistent with the peak in nitrogen fertilizer use in 1981; use has remained approximately at that level since (Alexander and Smith, 1990).

Total phosphorus

In streams, phosphorus occurs primarily as phosphate — dissolved, incorporated in organisms, or attached to particles in the water or bottom sediments. Total phosphorus refers to the sum of all forms.

A particularly important nutrient in freshwater ecosystems, phosphorus is usually the nutrient in shortest supply. Its availability often controls the rate of eutrophication. EPA recommends an upper limit of 0.1 mg/L as the standard for total phosphorus in streams (U.S. Environ. Prot. Agency, 1986). Algal biomass, water clarity, and dissolved oxygen depletion rate have been found to be strongly correlated with the loading rate of total phosphorus (Rast et al. 1983). The authors selected 0.1 mg/L and an arbitrary threshold of 0.5 mg/L for their analysis.

Average concentrations were 0.1 mg/L or greater at most of the 410 stations shown in Figure 5–5A. Concentrations greater than 0.5 mg/L were especially common in the central and south-central regions, where extensive agricultural use of phosphorus and highly erodible soils combine to create large nonpoint source loadings. Average total phosphorus concentrations show a higher concentration in agricultural areas but a wider range of concentrations in urban areas (fig. 5–5B).

Nationally, downward trends in total phosphorus occurred in 92 stations (fig. 5–5C). Downward trends occurred in all regions, but most frequently in the central States and the Great Lakes region. Upward trends occurred most frequently in the southeastern States. Nationally, the percentage of stations having annual average concentrations greater than 0.1 mg/L decreased gradually from 54 to 42 percent between 1982 and 1989 (fig. 5–5D).

Widespread declines in total phosphorus concentrations likely reflect significant reductions in point-source loads and some reduction in nonpoint-source loads. In addition to improvements in municipal and industrial wastewater treatment, the decrease since 1971 in phosphorus detergents helped reduce point source loads by an estimated 15 to 20 percent (U.S. Environ. Prot. Agency, 1990b). The reasons for changes in nonpoint source loads are more difficult to determine. However, phosphorus fertilizer use has declined more than 20 percent since 1979 (Alexander and Smith, 1990), and phosphorus contributions from livestock waste declined about 10 percent from 1982 to 1987 (U.S. Bur. Census, 1989; U.S. Dep. Agric. 1992).

Suspended sediment

Suspended sediment as well as bedload sediment comes from soil erosion. Because the quantities entering streams depend on natural factors, establishing national criteria for suspended sediment concentration is difficult. Smith et al. (1993) arbitrarily chose to study three suspended sediment concentrations — less than 100 mg/L, 100 to 500 mg/L, and greater than 500 mg/L.

Average concentrations were highest in the west-central regions and lowest in the north and south Atlantic States, Great Lakes, and Pacific Northwest. Throughout much of the central region, average concentrations were in the 100 to 500 mg/L range. High concentrations tended to occur in areas dominated by highly erodible soils (fig. 5–6).

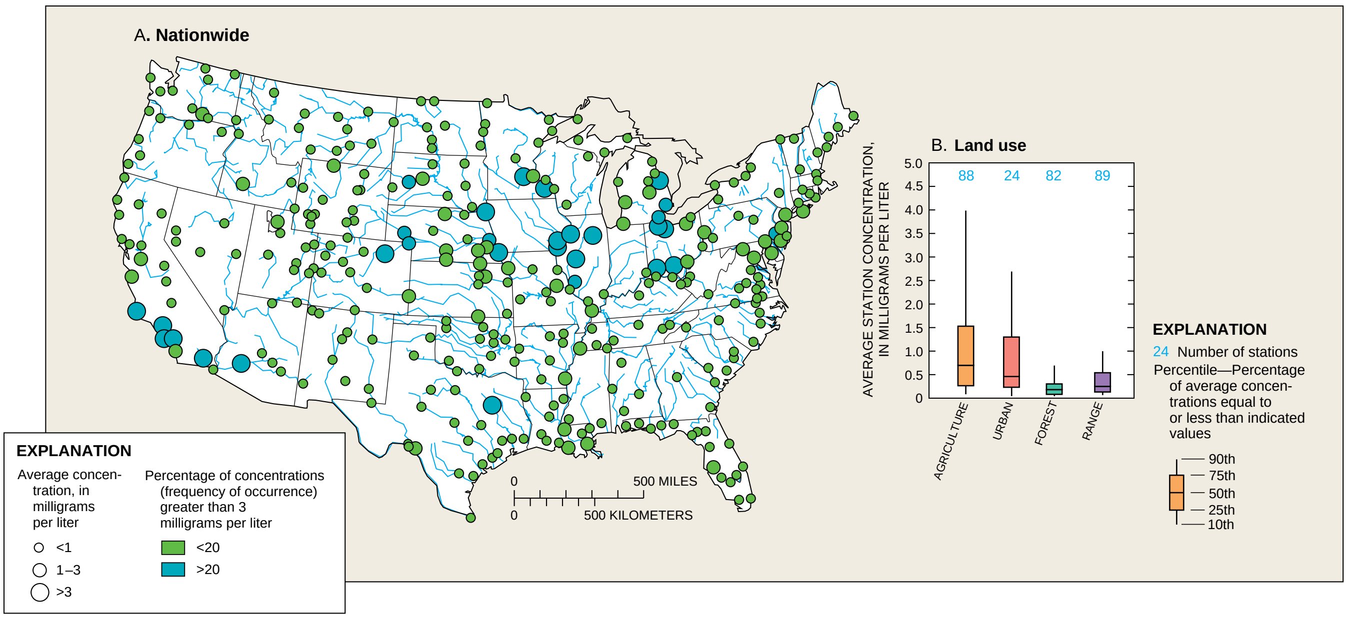
Downward trends in 37 stations, which greatly outnumbered upward trends in five stations, occurred mostly in the south-central regions and along the Gulf Coast (fig. 5–6C). Nationally, the percentage of stations having annual average concentrations greater than 100 mg/L declined from 37 to 31 percent (fig. 5–6D). The steepest decline in stations with concentrations greater than 500 mg/L occurred in areas dominated by range and agricultural land (fig. 5–6E). Increased efforts in soil conservation during 1980 to 1989 likely contributed, at least in part, to these trends. The NRCS (U.S. Dep. Agric. 1989) estimated that sheet and rill erosion on rural land, a category that includes crop and range land cover, decreased by 13 percent between 1982 and 1987.

Transport in streams and rivers

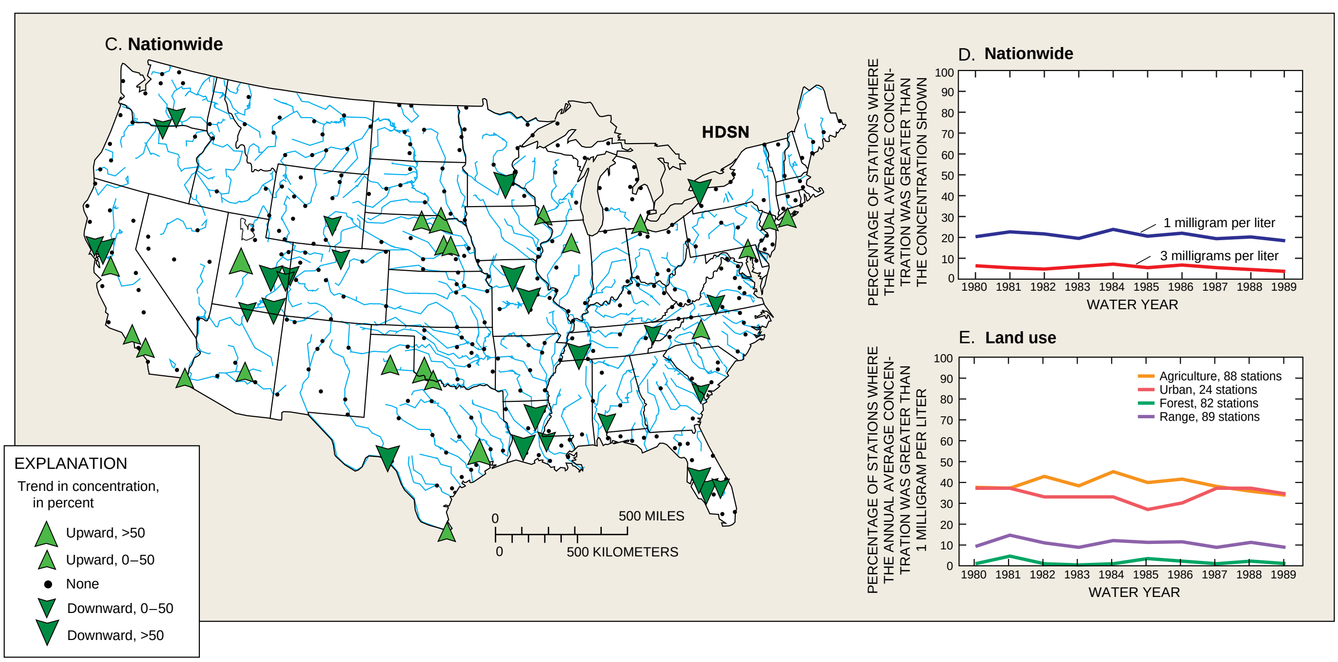
The transport of contaminants — nitrate, total phosphorus, and suspended sediment — from their source to downstream destinations is also of national concern. Even when concentrations in a stream are within desirable limits, large quantities of contaminants can

Figure 5-4 Concentration and trends in nitrate in stream water, 1980 to 1989 (Smith et al. 1993)

Average concentration



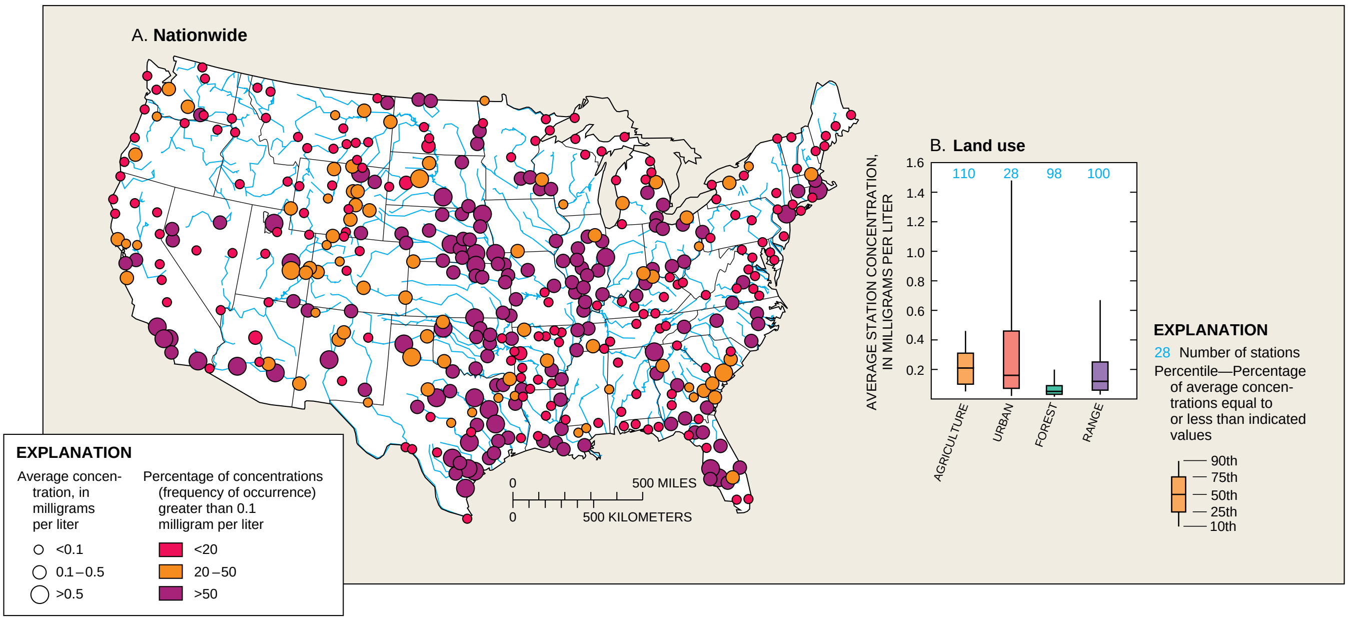
Trends in concentration



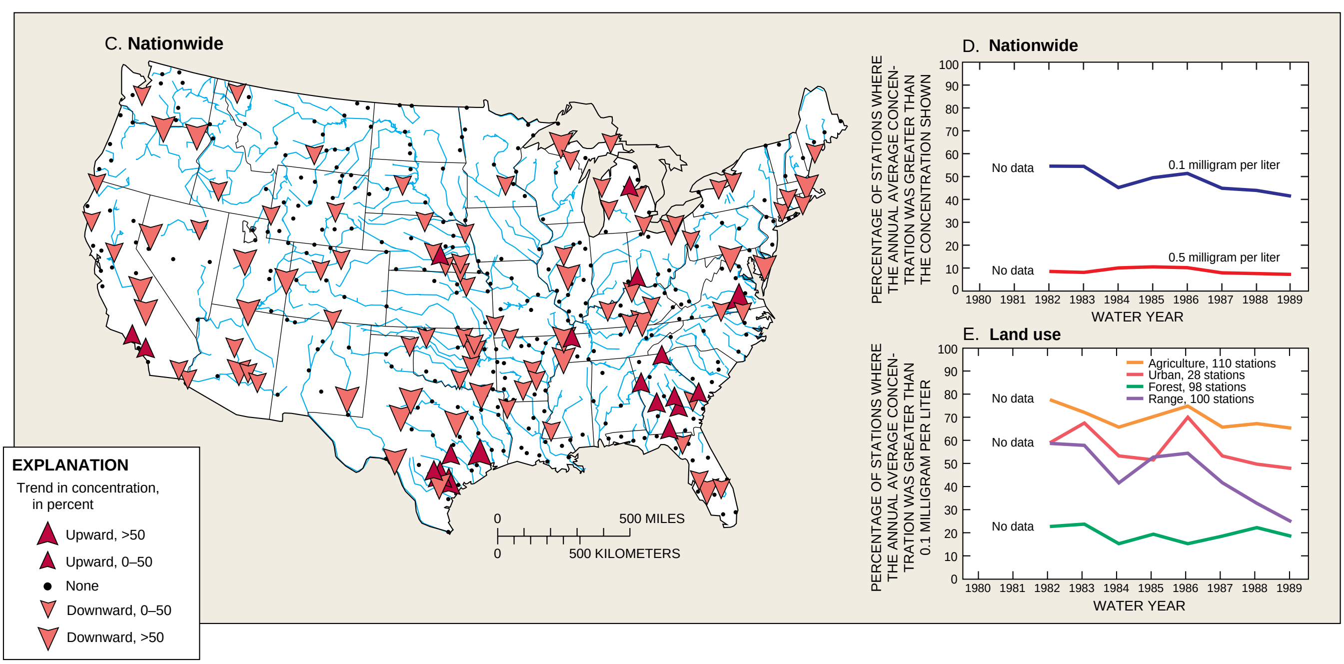
Concentration and trends in nitrate in stream water at 344 selected water-quality monitoring stations in the conterminous United States, water years 1980-89. A: Average concentration and percentage of concentrations greater than 3 mg/L (milligrams per liter) nationwide. B: Average concentration, by land use. C: Trends in concentration nationwide. D: Percentage of stations where the annnual average concentration was greater than 1 or 3 mg/L. E: Percentage of stations where the average concentration was greater than 1 mg/L, by land use (> greater than; < less than).

Figure 5-5 Concentration and trends in total phosphorus in stream water, 1982 to 1989 (Smith et al. 1993)

Average concentration



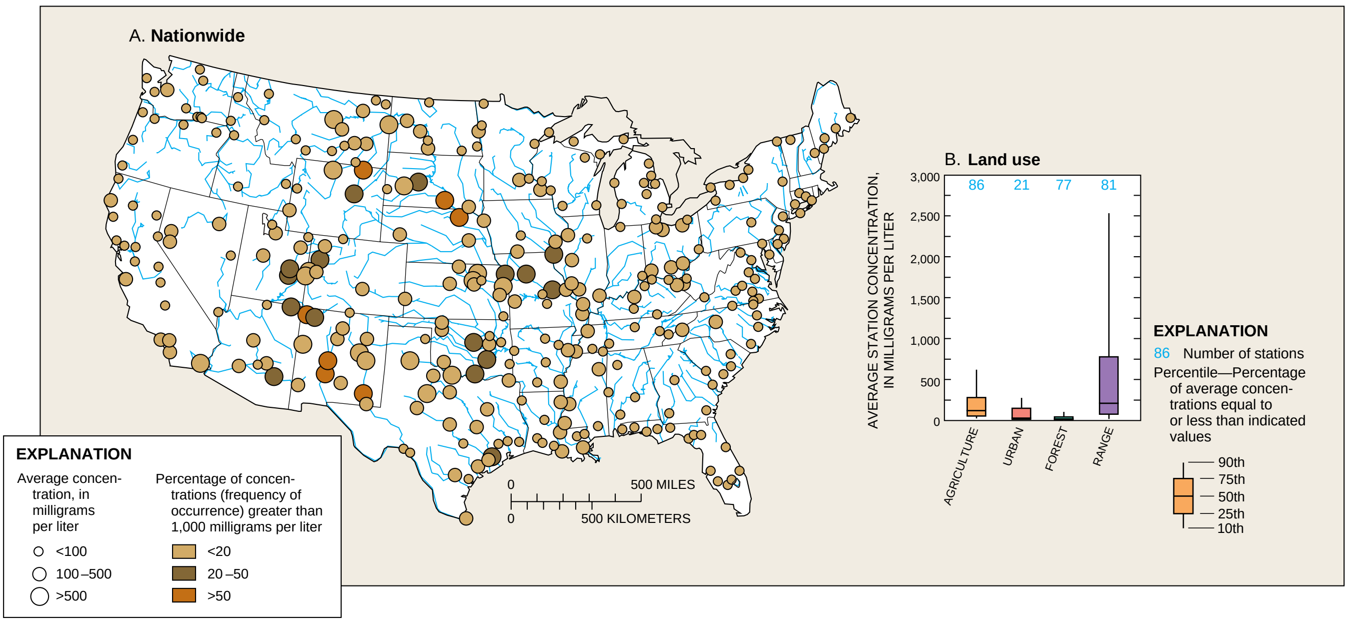
Trends in concentration



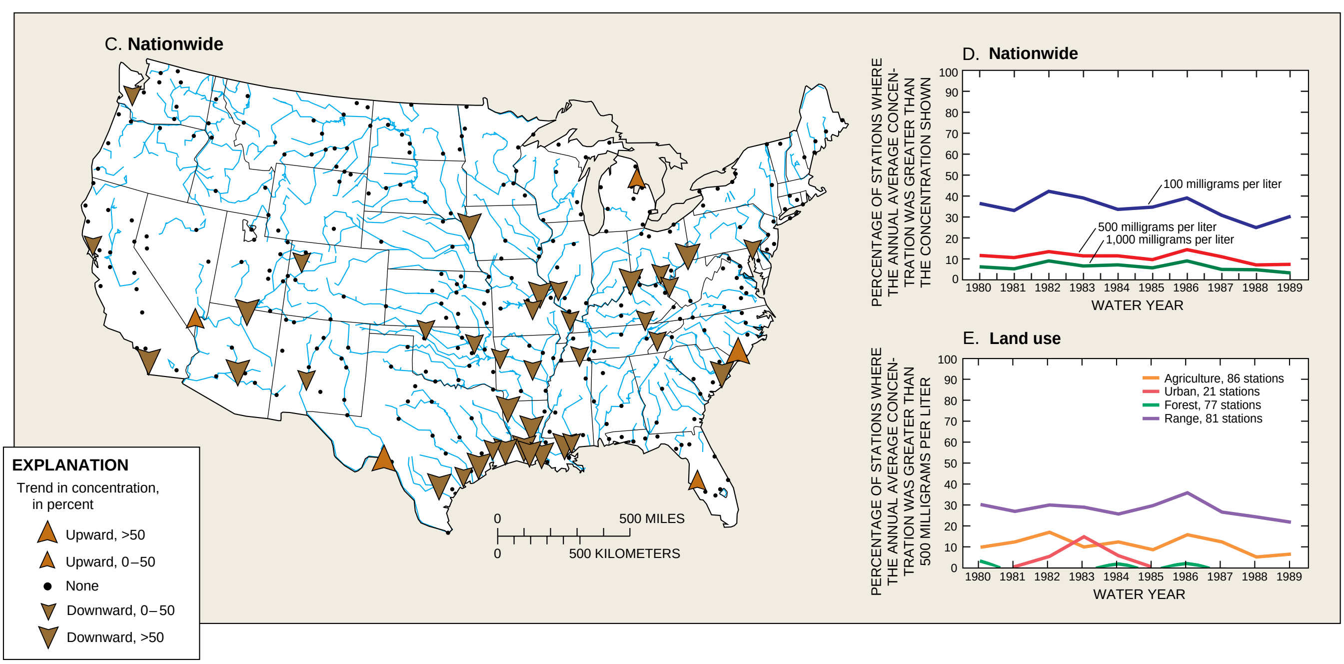
Concentration and trends in total phosphorus in stream water at 410 selected water-quality monitoring stations in the conterminous United States, water years 1982-89. A: Average concentration and percentage of concentrations greater than 0.1 mg/L (milligrams per liter) nationwide. B: Average concentration, by land use. C: Trends in concentration nationwide. D: Percentage of stations where the annnual average concentration was greater than 0.1 mg/L. E: Percentage of stations where the annual average concentration was greater than 0.1 mg/L, by land use (> greater than; < less than).

Figure 5-6 Concentration and trends in suspended sediment in stream water, 1980 to 1989 (Smith et al. 1993)

Average concentration



Trends in concentration



Concentration and trends in suspended sediment in stream water at 324 selected water-quality monitoring stations in the conterminous United States, water years 1980-89. A: Average concentration and percentage of concentrations greater than 1,000 mg/L (milligrams per liter) nationwide. B: Average concentration, by land use. C: Trends in concentration nationwide. D: Percentage of stations where the annnual average concentration was greater than 100, 500, or 1,000 mg/L. E: Percentage of stations where the annual average concentration was greater than 500 mg/L, by land use (> greater than; < less than).

be transported downstream to more sensitive environments, where they can accumulate through sedimentation, evaporation, or biological uptake. "Load" is the quantity of contaminants transported during a specific period, such as tons per year. "Yield" is load divided by unit drainage area, such as tons per year per acre. Yield is a useful measure for comparing loads among basins of differing size. Lakes, reservoirs, estuaries, and other coastal water are particularly affected by the accumulation of stream-transported constituents.

During the analysis period, yields of nitrate and total phosphorus were highest in the Upper Mississippi and Ohio-Tennessee regions and lowest in the Souris-Red-Rainy and Texas-Gulf-Rio Grande regions (fig. 5–7). The geographic pattern of nutrient yields reflects regional differences in land use and runoff, and it differs from the geographic pattern of nutrient concentrations shown in Figures 5–4A and 5–5A. For example, total phosphorus concentrations were high in streams draining the Texas-Gulf-Rio Grande region; whereas, total phosphorus yields in the same streams were low because of low average runoff (fig. 5–7).

Suspended sediment yields followed a geographic pattern similar to that of nitrate and total phosphorus. Yields were high in the Ohio-Tennessee, Upper and Lower Mississippi, and Colorado regions. Suspended sediment yields were much greater than nutrient yields. Over the 1980 to 1989 period, the annual percentage of nitrate yields changed little, a stark contrast to the 1974 to 1981 period during which widespread increases in nitrate were reported (Smith et al. 1987). With the exception of the South Atlantic-Gulf region, where the annual change in total phosphorus yield was an increase of 0.1 percent, annual changes decreased slightly in all regions and substantially in the Great Lakes, Arkansas-White-Red, and Lower Mississippi regions. The pattern of widespread decreases in total phosphorus yield is consistent with that of concentration trends.

Suspended sediment yields decreased slightly in all regions except the Souris-Red-Rainy, Great Lakes, and South Atlantic-Gulf regions, where yields increased slightly. As noted under concentration trends, the national trend toward moderate decreases in suspended sediment yields during the 1980s is the result, in part, of increased soil conservation efforts.

Land use effects on nutrients and sediment transport

Much of the geographic variation in yields of nitrate, total phosphorus, and suspended sediment results from differences in land use. For example, yields in the Ohio-Tennessee and Upper Mississippi regions are the result of extensive agricultural activity and relatively high population density. Figure 5–8 shows the average of the eight or 10 year median flow adjusted station yields of nitrate, total phosphorus, and suspended sediment for the four land-use classes.

Figure 5–8 shows that in agricultural areas, nitrate, total phosphorus, and suspended sediment yields were highest in areas under corn and soybean cultivation. Yields were lowest in units under wheat cultivation and moderate to high in units dominated by mixed agriculture (wheat, corn, soybeans). The differences in yield result from factors such as fertilizer composition and application rates, tillage practices, climate, and soil characteristics that have an influence on either nutrient and suspended sediment availability or on runoff.

Not surprisingly, nitrate and total phosphorus yields were high in urban areas, largely as a result of point-source contributions. In contrast, these yields were low in units dominated by forest and rangeland. The factors that limit yields in forest and rangeland dominated by nonagricultural vegetation are forest cover that limits soil erosion and low precipitation rate.

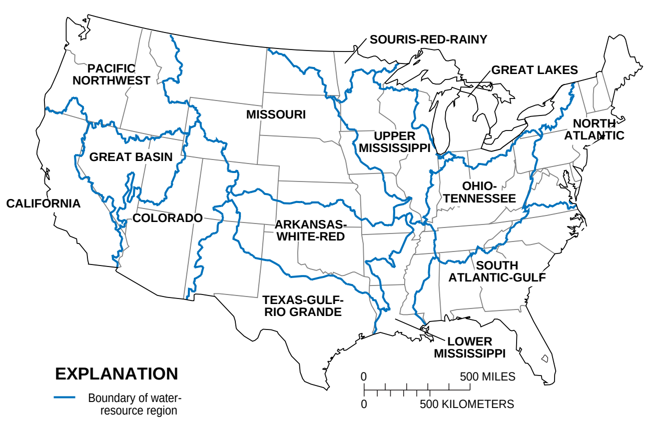
Changes within a land use class may also cause yield changes. For example, the lack of a major change in nitrate yields in agricultural basins during the 1980s may reflect a leveling off in the quantities of nitrogen fertilizer used nationally since 1981 (Alexander and Smith, 1990).

Mueller, Ruddy, and Battaglin (1993) support this relationship between land use and water quality. They correlated nitrate concentrations in streams and streamflow with agriculture census data (acres of corn and soybeans, density of cattle numbers, population density) in 10 midwestern States and found that regional water quality conditions can be reasonably analyzed with large-scale land use data, such as that derived from census. Relying on data retrieved from large GIS databases that had county-level resolution, researchers could correctly classify 80 percent of the observed nitrate concentrations in outflow from a variety of river basins.

Decreases in total phosphorus yield were greatest in agricultural and range areas. During 1980 to 1985, phosphorus fertilizer use decreased nationally by 16 percent (Alexander and Smith, 1990), and the general trend toward declining erosion rates and suspended sediment yields in rural areas also began during this period (U.S. Dep. Agric. 1989).

Early in the 1980s, suspended sediment yields in most areas reached peak values; they decreased substantially by the end of the decade. Only the yields in areas dominated by wheat cultivation increased. Yield decreases in streams may reflect the expansion of conservation tillage during the 1980s and decreases in soil erosion rates between 1982 and 1987. Cropland under conservation tillage increased from 18 to 42 percent for the Northeast, 34 to 42 percent in the Great Lakes and Midwest, and 10 to 23 percent in the southern Great Plains (Conserv. Tech. Inf. Center, 1982 and 1988).

Figure 5-7 Yield and percentage change in yield of nitrate, total phosphorus, and suspended sediment in 14 water-resources regions of the conterminous United States (Smith et al. 1993; water-resources regions modified from Seaber et al. 1987)



WATER-RESOURCES REGION SHOWN ON MAP	NITRATE 1980–89		TOTAL PHOSPHORUS 1982–89		SUSPENDED SEDIMENT 1980–89	
	Yield, in tons per square mile per year	Percentage change per year	Yield, in tons per square mile per year	Percentage change per year	Yield, in tons per square mile per year	Percentage change per year
North Atlantic	0.558	*	0.077	–1.4	32	–0.4
South Atlantic-Gulf	0.226	*	0.092	+0.1	20	+0.2
Great Lakes	0.647	*	0.067	–3.3	36	+0.5
Ohio-Tennessee	0.847	*	0.125	–1.0	85	–1.3
Upper Mississippi	0.989	–0.4	0.157	–1.2	102	–1.3
Lower Mississippi	0.333	–1.6	0.103	–3.8	111	–1.2
Souris-Red-Rainy	0.011	*	0.008	–0.8	4	+1.2
Missouri	0.060	*	0.028	–1.7	45	–0.2
Arkansas-White-Red	0.056	*	0.039	–3.1	31	–0.7
Texas-Gulf-Rio Grande	0.012	*	0.014	–0.9	15	–0.6
Colorado	0.057	*	0.036	–2.4	92	–0.8
Great Basin	0.049	*	0.018	–2.7	21	–0.2
Pacific Northwest	0.225	*	0.063	–1.7	40	–0.1
California	0.047	*	0.060	–1.4	21	–0.6

* Between –0.1 and +0.1.

Missouri Sedimentation From 1993 Flood

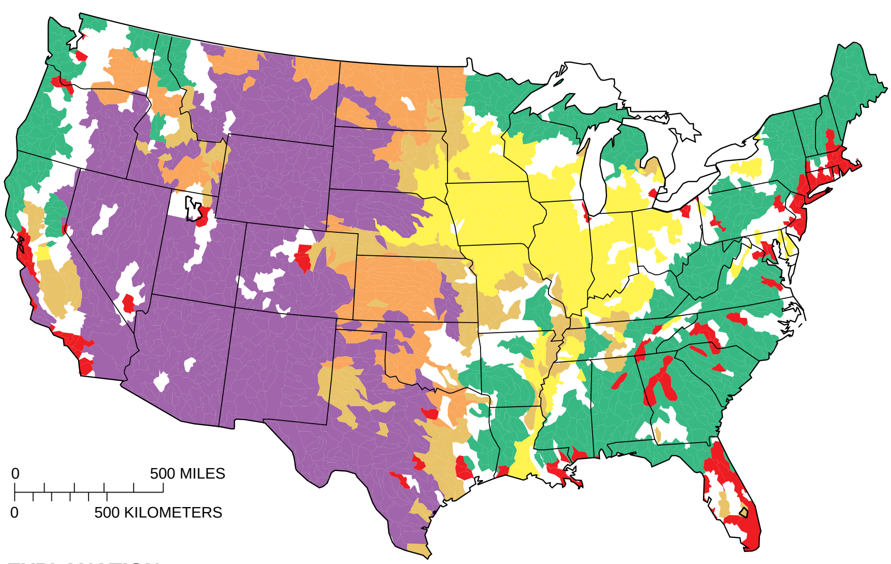
Following the 1993 flood, Missouri farmers had to bulldoze and scrape away the sterile blanket of sand covering their fields. Some 500,000 acres—about 60 percent of Missouri River bottom land—was covered by sand, from a thin layer to a blanket as thick as 10 feet. The impact of sand deposits on crop production depended on the sand depth and the texture of the buried original topsoil. Generally, bringing cropland back into efficient production is extremely difficult when infertile, sterile sand deposits are greater than one foot thick. Heavy-duty nonfarming equipment is required to cut through the sand and into the buried topsoil deep enough to mix the infertile with the fertile soil. If the buried soil is sandy, the recovery prospects are remote unless the infertile sand is actually scraped off and transported off the farm. The estimated costs to recover Missouri's sand-blanketed bottomlands was $300 million or more (Bernard et al. 1994).

Herbicides transport

In 1993, herbicides in drinking water became more significant for water utilities as monitoring requirements in the Safe Drinking Water Act became effective. If the running average of four consecutive samples at a facility exceeds the established drinking water standard, the EPA can require the utility to find an alternative water supply or treat the water to reduce contaminant concentration.

A recent study of herbicide occurrence is an exception to the general lack of information on pesticide concentration in streams. This study includes a random sample of 149 streams draining agricultural basins in a 10-State region of the Midwest (Goolsby, Thurman, and Kolpin, 1991; Thurman et al. 1991). Although this study is regional rather than national, about three-quarters of all preemergent herbicides used in the United States are applied in the study region. The study area and the concentrations of selected herbicides in streams are shown in figure 5–9. The herbicide concentrations reported are for untreated stream water, whereas the EPA maximum contaminant levels and lifetime health advisory levels apply to treated water. Conventional water supply treatment processes generally do not remove these herbicides from water

Figure 5-8 Yield and percentage change in yield of nitrate, total phosphorus, and suspended sediment in hydrologic cataloging units in the conterminous United States classified with agricultural (wheat, corn, and soybeans, and mixed), urban, forest, and rangeland use (Smith et al. 1993)



EXPLANATION

LAND USE SHOWN ON MAP	NITRATE 1980–89		TOTAL PHOSPHORUS 1982–89		SUSPENDED SEDIMENT 1980–89	
	Yield, in tons per square mile per year	Percentage change per year	Yield, in tons per square mile per year	Percentage change per year	Yield, in tons per square mile per year	Percentage change per year
AGRICULTURE Wheat	0.032	*	0.010	–2.8	10	+0.8
Corn and soybeans	0.932	*	0.163	–2.1	100	–1.0
Mixed	0.304	*	0.066	–1.6	79	–0.7
URBAN	0.547	+0.2	0.119	–0.6	23	–0.6
FOREST	0.255	*	0.063	–0.8	31	–0.3
RANGE	0.031	*	0.017	–1.9	33	–0.2

*Between –0.1 and +0.1.

(Miltner et al. 1989). About 18 million people in the drainage basins within the 10-State area rely on surface water for drinking water supplies.

The study found that detectable concentrations of atrazine, one of the most commonly used herbicides for weed control in corn and sorghum production, occurred year-round in a majority of the streams. Atrazine breaks down more slowly than other current generation pesticides and is detectable in surface water longer after application; little, however, is carried over from season to season.

During the first runoff after application in 1989, 52 percent of the streams sampled had atrazine concentrations exceeding 3 µg/L, the EPA-recommended MCL for drinking water. During the spring and early summer following application, concentrations increased by as much as two orders of magnitude; by fall, they fell to preapplication levels during low streamflow conditions. Because of the random sampling design, these results are probably typical of streams throughout the study region.

For three other herbicides (alachlor, cyanazine, and simazine), the number of sampling locations with concentrations exceeding the EPA drinking water criteria immediately after application ranged from 2 to 49 percent. In 32 percent of the streams sampled, concentrations of alachlor exceeded the EPA MCL for drinking water of 2 µg/L (Goolsby, Thurman, and Kolpin, 1991). When compared to the most recent EPA drinking water criteria, concentrations of cyanazine exceeded the lifetime health advisory level of 1 µg/L at 49 percent of the streams sampled; concentrations of simazine exceeded the MCL of 4 µg/L at only 2 percent of the streams sampled.

The widespread occurrence of herbicides in medium-sized streams in the Midwest prompted questions about their magnitude and distance of transport. In spring 1991, as a follow-up to the first survey, the USGS initiated sampling for five herbicides in the Mississippi River and several major tributaries (Goolsby, Coupe, and Markovchick, 1991). In every sample collected from April to June, one or more herbicides were detected. Atrazine was detected most frequently, followed by cyanazine, alachlor, and simazine. Concentrations of atrazine and alachlor occasionally exceeded MCLs for drinking water. Atrazine exceeded the MCL in 27 percent of the samples, including one sample from the Mississippi River at Baton Rouge, hundreds of miles from the major source of atrazine use in the Midwest. Alachlor exceeded the MCL in 4 percent of the samples, but only in the smaller tributaries.

Atrazine load calculations indicate that the largest percentage — about 37 percent — of the atrazine discharged from the Mississippi River into the Gulf of Mexico entered the river from streams draining Iowa and Illinois. The second largest source area was the Missouri River basin, which contributed about 25 percent of the atrazine entering the Gulf. Some 517,000 pounds of atrazine were discharged to the Gulf of Mexico from April through June 1991, representing slightly less than 1 percent of the atrazine applied annually to Mississippi basin cropland.

Using data from 1984 to 1989, Richards and Baker (1993) and others conducted a systematic assessment of atrazine exposures through drinking water for Ohio and Illinois populations and for the Iowa population served by public water supplies. The assessments indicate that atrazine exposure does not represent a human health threat. Exposures above the lifetime HAL do not exceed 0.25 percent in these States; 94 to 99 percent of the water supplies sampled have exposure concentrations less than 1 ppb. The highest concentrations are associated with private wells and a few small public water supplies drawing on ground water. The wells are typically shallow and often draw on alluvial aquifers. High concentrations usually stem from contamination from a nearby chemical dealer or from accidents or improper pesticide handling on the farm. On average, assessed populations are exposed to concentrations less than one-tenth of the MCL.

Lakes and reservoirs

Contaminant transport to selected reservoirs

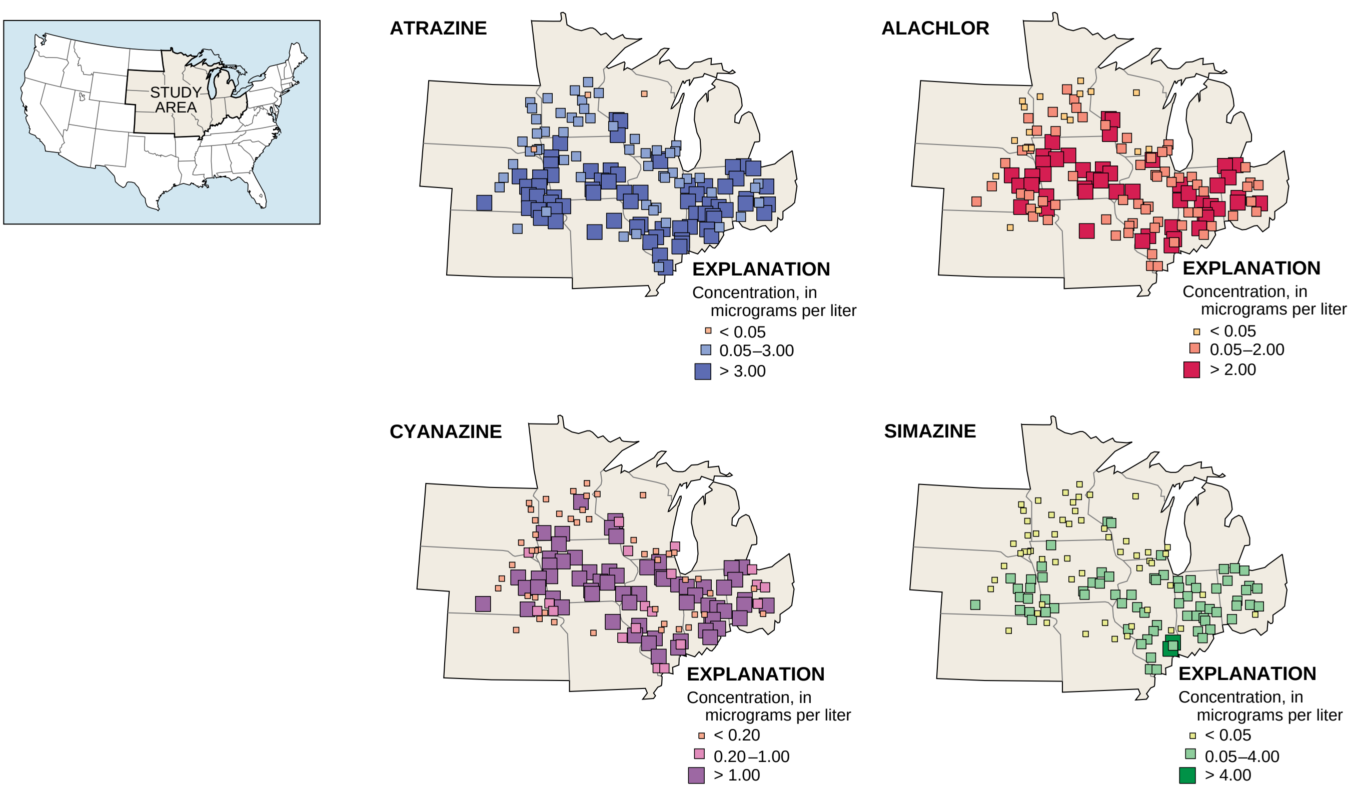
Much of the particulate material transported by streams is removed before a stream reaches coastal water. Biological uptake is primarily responsible for the removal of nitrate, whereas reservoirs are major repositories for phosphorus and sediment. Total phosphorus and suspended sediment loads were calculated for monitoring stations located no more than 25 miles upstream of reservoirs having a normal storage capacity greater than 5,000 acre-feet. The 85 stations that met this criterion (fig. 5–10A) have a geographic distribution similar to that of large reservoirs throughout the conterminous United States (Ruddy and Hitt, 1990).

Total phosphorus loads are strongly correlated with several important indicators of eutrophication, including the Vollenweider Index. Index values between 0.05 mg/L and 0.3 mg/L indicate moderately eutrophic conditions; values greater than 0.3 mg/L indicate highly eutrophic conditions. The percentage of reservoirs having index values above the lower threshold of the moderately eutrophic range decreased from 67 to 57 percent, but the percentage having index values above the threshold for highly eutrophic water increased from about 11 to 15 percent (fig. 5–10B). The increase in the percentage of reservoirs with high values contrasts with the general national pattern of moderate decreases in total phosphorus concentrations and loads.

Reservoir sedimentation rates

A preliminary analysis of reservoir sediment records collected from 1930 to 1985 suggests that sediment deposition rates have been increasing (Atwood and Steffan, 1994). No reservoir sediment accumulation data since the mid-1980s are available. During the 1970 to 1985 period, the accumulation rate averaged 0.66 acre-feet per square mile per year, more than triple the 1930 to 1950 rate. The analysis predicted that by 1993 about 40 percent of the 1,600 reservoirs in the database would be half full of sediment.

Figure 5-9 Concentrations of selected herbicides collected during the first runoff after spring 1989 application in streams draining agricultural areas in 10 midwestern States (Smith et al. 1993)



Concentrations of selected herbicides collected during the first runoff after application in the spring of 1989 in streams that drain agricultural areas in a 10-state area in the Midwest. Highest concentration interval in each map is the U.S. Environmental Protection Agency maximum contaminant level (MCL) for drinking water (>, greater than; <, less than).

Atwood and Steffan's conclusion — that sediment continues to be produced at levels near those of the early 1980s — contrasts with the declining rates found by USGS. Sheet and rill erosion was indeed reduced during the 1980s. However, little reduction, or perhaps even increases occurred in off-the-field erosion, such as streambank and classic gully erosion. Conservation practices that reduce field erosion and off-the-field sediment loads to the stream will increase streambank erosion in some areas by increasing hydraulic energy. The apparent inconsistency in the two reports does not suggest that one is more accurate — rather, it points out that the full sedimentation picture remains cloudy.

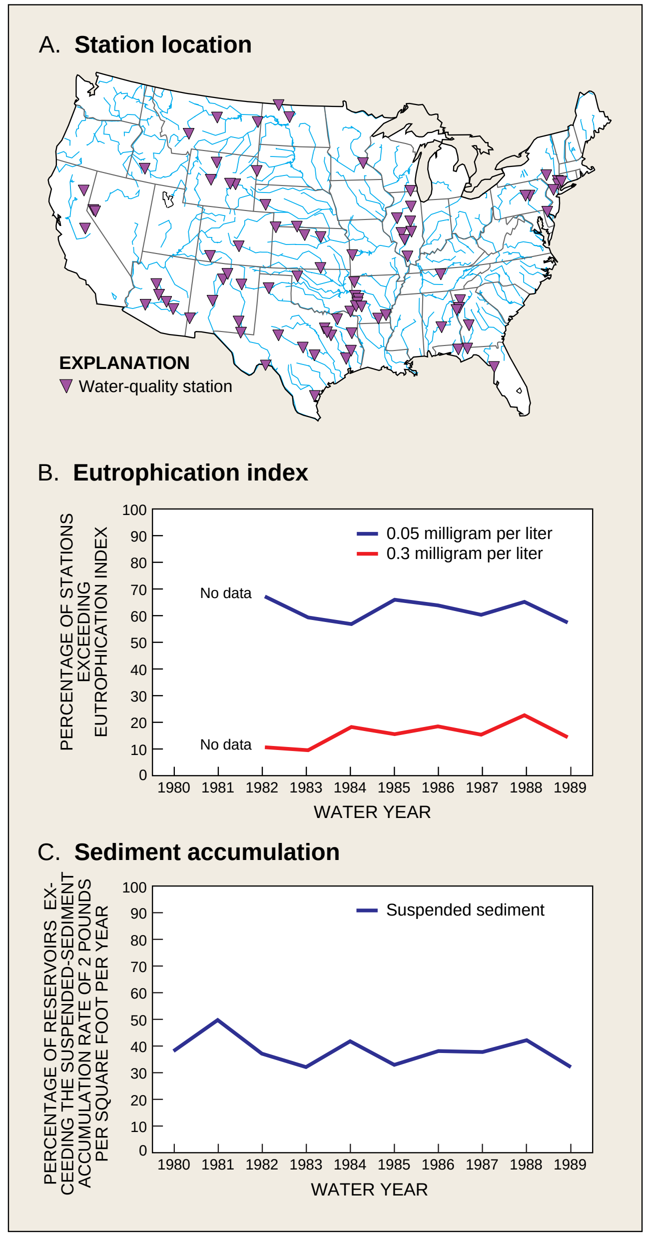
Comparing sediment deposition rates for reservoirs in different drainage area classes seems, however, to corroborate the well-documented correlation of decreasing sediment yield with increasing drainage area. Reservoirs with the smallest drainage areas average about 1.15 acre-feet per square mile per year; reservoirs with large drainage areas (>5,000 square miles) average about 0.17 acre-feet per square mile per year.

Further analysis shows that

- More sediment deposition occurred during the 1950 to 1970 period than in any other period. However, the annual rate of sediment deposition decreased from 1950 to 1970 to 75 percent of the 1930 to 1950 rate.
- The annual sediment deposition rate increased almost fivefold in the 1970 to 1985 period compared with the 1950 to 1970 period.

Conservation practices on agricultural land that significantly reduce sediment yield include buffer strips, filter strips, constructed wetlands, terraces, water and sediment control structures, gully plugs, diversions, and sediment basins. Because reductions in off-the-field sediment loads from conservation practices will increase streambank erosion in some areas, streambank erosion controls and restoration techniques will be needed.

Figure 5-10 Water quality of tributaries to 85 selected large reservoirs, 1980 to 1989 (Smith et al. 1993)



Water quality of tributaries of 85 selected large reservoirs, 1980-89. A: Location of water-quality monitoring stations. B: Percentage of stations exceeding eutrophication index values of 0.05 mg/L (milligrams per liter) and 0.3 mg/L/ C: Percentage of reservoirs whose suspended-sediment accumulation exceeded 2 pounds per square foot per year.

Pesticides in rainfall and surface water

- A study of 76 midwestern reservoirs shows that commonly used herbicides and their metabolites are detected more frequently and at higher concentrations throughout the year in reservoirs than in streams. Herbicides were detected in 82 to 92 percent of the 76 reservoirs sampled four times from April to November 1992. Atrazine and alachlor were most frequently detected. These findings suggest that herbicides live longer in reservoirs than in streams. Even so, concentrations of one or more herbicides exceeded MCLs or HALs in only eight reservoirs sampled before planting (April-May), 16 reservoirs sampled after planting (June-July), 7 reservoirs sampled in late summer, and 2 reservoirs sampled in the fall (Goolsby et al. 1993).

- A USGS study site in the Albemarle-Pamlico basin found commonly used pesticides such as atrazine and alachlor were almost always detectable in streams (Leahy, 1995). Concentrations were highest in spring rains, but remained detectable even during periods of low flow. About 7 percent of the samples had concentrations above the MCL.

- In a USGS study site in Georgia, more pesticides were detected in streams of a suburban watershed than in agricultural watersheds (Leahy, 1995). Pesticides found in the agricultural watersheds tended to show seasonal patterns, while those in the nonagricultural watersheds were persistent throughout the year.

- USGS found that 14 herbicides, five insecticides, and one fungicide were detected in flood water of the Flint and Ocmulgee Rivers in Georgia. All pesticide concentrations were well below EPA standards and guidelines for drinking water. However, concentrations of the insecticides chlorpyrifos, carbaryl, and diazinon approached or exceeded recommended guidelines for protection of aquatic life (USGS 1995a).

Rainfall is an important source of pesticides to surface water. Most of the commonly used pesticides found in the atmosphere originate from spray drift and evaporation and often return to earth in rainfall (USGS 1995b). An Iowa study of pesticides in spring rain water commonly detected alachlor and atrazine — the atrazine in concentrations approaching 1 ppb (Baker, Adcock and Miller, 1992). The highest concentrations occur seasonally in high-use areas when applications are greatest. Because airborne chemicals can travel long distances before being deposited again with rainfall, low levels of long-lived pesticides can also be found in areas where little or no pesticide application occurs. Atmospheric deposition of pesticides is most likely when precipitation and direct surface runoff are the major sources of streamflow. The full significance of pesticide-contaminated rainfall for water quality is largely unknown, however, because of the small number of studies conducted to date.

River and stream water quality — conclusions

Smith et al. (1993) drew a number of conclusions from their analysis. During the 1980s, concentrations of several traditional sanitary and chemical water quality indicators decreased. This collectively provides evidence of progress in pollution control during the decade. The most notable improvements occurred in concentrations of fecal coliform bacteria and total phosphorus. Widespread declines also occurred in the total phosphorus load transported to large reservoirs and coastal water. However, more than one-third of the streams sampled in 1989 had annual average concentrations of total phosphorus and fecal coliform bacteria that exceeded desirable limits.

Trends in other indicators showed slight improvements or little change in stream water quality during a decade in which the economy and population showed significant growth. For example, dissolved oxygen concentrations changed little nationally from 1980 to 1989, but streams in urban areas showed slight improvement. Similarly, nitrate concentrations and yields remained nearly constant nationally, but they declined in a number of streams draining agricultural areas where nitrate levels were historically high. This general tendency toward constant or declining nitrate concentrations represents a significant departure from the trend pattern for 1974 to 1981, when widespread increases in nitrate were reported. Nitrate transport decreased to the Gulf of Mexico but increased somewhat in the North Atlantic and California coastal segments. Suspended sediment concentrations and yields decreased slightly in most of the country, and the quantity of suspended sediment transported to coastal regions decreased or remained the same in all but the North Atlantic region.

Although national data on pesticide trends in stream water are not available, recent studies of the Midwest from 1989 to 1991 provide important regional information on herbicides. These studies show that in 1989 during the first runoff following application, atrazine exceeded drinking water criteria at 52 percent of the streams sampled; for alachlor, cyanazine, and simazine, 2 to 49 percent of the streams sampled exceeded the criteria. In many streams, substantially lower but detectable concentrations persisted throughout the year. In the Mississippi River and its major tributaries, additional sampling for these herbicides showed that alachlor and atrazine occasionally exceed EPA drinking water criteria and substantial quantities of these herbicides are transported over long distances by major rivers.

In sum, most available measures show that stream water quality in the conterminous United States either improved or remained about the same during the 1980s. Although modest improvements in water quality during this period of economic growth represent a significant achievement in pollution control, much work remains to reach existing water quality stan-

Lake Erie

In contrast to land use in the other Great Lakes watersheds, Lake Erie’s dominant land use is row-crop agriculture. Lake Erie tributaries carry, on average, larger loads of nutrients, sediments, and pesticides than do tributaries entering the other lakes. Phosphorus and sediment loads entering Lake Erie are of greater concern than nitrate pollution. Conservation tillage is especially desirable because it reduces particulate phosphorus exports and environmental costs associated with erosion.

Trends in tributary loads and concentrations from nonpoint sources are difficult to document because they fluctuated widely from year to year and may reflect volatile flows driven by storm events during the year. However, using monitoring data collected since the mid-1070s, Richards and Baker (1993) have found statistically significant downward trends in soluble reactive phosphorus over the 1975 to 1990 period. Suspended sediment has experienced a slight decreasing trend but is generally not statistically significant. Nitrate-plus-nitrite has shown a significant increasing trend.

Although the importance of the sources of change is difficult to determine, point source contributions and reductions in these agricultural basins may be outweighed by nonpoint sources. The ban on phosphate detergents since the 1970s also led to a significant reduction in phosphorus from point sources. An approximate 25 percent reduction in phosphorus fertilizer sales over the period and increased acreage in conservation tillage and conservation set-asides, both of which would increase infiltration, support this tentative conclusion.

Richards and Baker (1993) found high seasonal concentrations of herbicides during May through July—the months of application and runoff. Monthly time-weighted maximum contaminant levels of atrazine frequently exceeded its MCL, an annual average concept. However, time-weighted MCLs of various herbicides (atrazine, alachlor, cyanazine and others) for 1983 to 1991 are below their MCLs at stations on major tributaries.

Monitoring programs included analyses for various insecticides but could seldom detect them; insecticides have lower application rates and degrade more rapidly than herbicides (Richards and Baker, 1993; Baker, 1993).

dards for the current nationally monitored indicators. Moreover, the fragmentary biological and toxicological data on stream water quality leaves the question of progress largely unanswered.

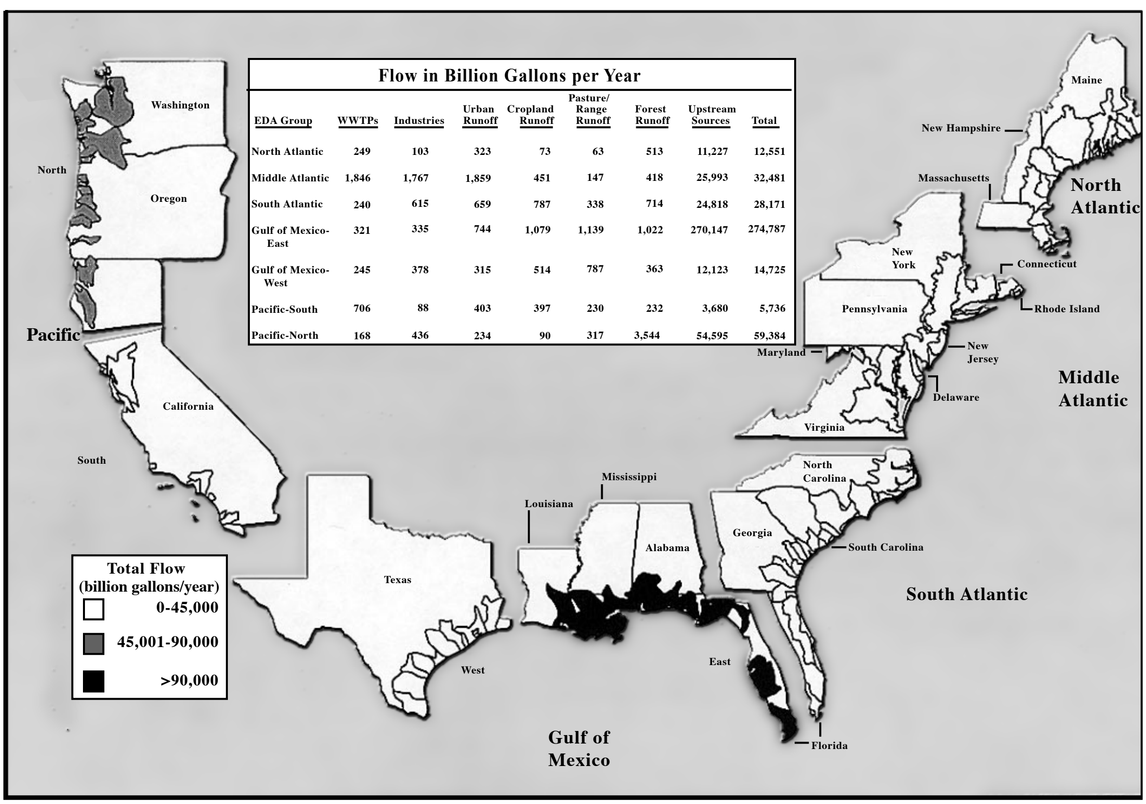
Major estuaries

“Estuaries are semi-enclosed coastal bodies of water having a free connection with the open sea and within which seawater is diluted measurably by fresh water from land drainage” (NOAA 1990).

NOAA has established estuarine drainage areas (EDAs) as the basis of its data collection and analyses. As areas closest to the coast, EDAs may have the greatest effect on water. Figure 5–11 shows the distribution and areal extent of EDAs grouped by major coastal regions — North Atlantic, Middle Atlantic, South Atlantic, East Gulf of Mexico, West Gulf of Mexico, South Pacific, and North Pacific. Table 5–1 displays selected physical, hydrologic, natural resource, and economic characteristics of these coastal regions.

The ability to flush out or dilute pollutants is one measure of an estuary’s susceptibility to changes in pollution. Pollutants may enter the EDA either in dissolved form or attached to suspended particles in water. NOAA developed a relative index, based on estuarine physical and hydrologic factors, that indicates an estuary’s degree of susceptibility to a reduction or an increase in pollutant inputs (NOAA, 1990). Estuaries in the North and Middle Atlantic regions

Figure 5-11 Total flow estimates in coastal regions by major source category, 1982 to 1987 (NOAA. 1994)



Flow in Billion Gallons per Year

EDA Group	WWTPs	Industries	Urban Runoff	Cropland Runoff	Pasture/ Range Runoff	Forest Runoff	Upstream Sources	Total
North Atlantic	249	103	323	73	63	513	11,227	12,551
Middle Atlantic	1,846	1,767	1,859	451	147	418	25,993	32,481
South Atlantic	240	615	659	787	338	714	24,818	28,171
Gulf of Mexico-East	321	335	744	1,079	1,139	1,022	270,147	274,787
Gulf of Mexico-West	245	378	315	514	787	363	12,123	14,725
Pacific-South	706	88	403	397	230	232	3,680	5,736
Pacific-North	168	436	234	90	317	3,544	54,595	59,384

have the highest sensitivities to both dissolved and particulate attached pollutants. South Atlantic and Gulf of Mexico regions generally have lower sensitivities, except in the Texas lagoonal bar-built estuaries. Pollution-retention sensitivity varies greatly in the Pacific regions because of the many estuary types (river dominated, coastal bays, and fjords).

NOAA's National Coastal Pollutant Discharge Inventory (NCPDI) Program presents loading estimates for point, nonpoint, and riverine sources in coastal counties that discharge to EDAs. Estimates come from combining monitoring data and engineering values for "typical" agricultural activities for different years during the 1982 to 1987 period. Because estimates differ among EDAs by year, weather, and completion, estimates are not fully comparable. The tabular data in Figures 5–11, 5–12, and 5–13 summarize the EDA estimates to the seven larger coastal regions to improve comparability.

The tabular data in Figures 5–11 to 5–13 show that nearly all wastewater discharge and surface runoff flow to the seven regions come from upstream sources above the limit of tidal influences. Regarding total nitrogen and phosphorus loadings, this qualification is true for one region — the east Gulf of Mexico. In each of the other regions, pollutant sources within the EDAs are important.

Table 5-1 Selected characteristics of the Nation's major estuaries, selected years 1982 to 1987

Characteristic		Major Estuary Regions					
Physical/Hydrologic	**Units**	**North Atlantic**	**Middle Atlantic**	**South Atlantic**	**Gulf of Mexico**	**Pacific**	**United States**
Estuarine drainage	(1,000 mi^2)	23	48	55	96	36	260
Total drainage	(1,000 mi^2)	36	123	145	1,562	362	2,251
Water surface	(1,000 mi^2)	2	7	4	12	2	27
Average daily freshwater inflow	(1,000 ft^3)	65	172	158	970	449	1,814
Natural Resource							
Wetlands	(100 mi^2)	12	35	92	166	18	323
Classified shellfish waters	(100 mi^2)	12	74	40	88	5	210
Economic							
Urban area	(% of EDA)	7	19	4	5	12	9
Agricultural area	(% of EDA)	7	27	22	30	11	23
Industrial point sources	(100)	2	18	4	20	7	51
Municipal wastewater treatment plants	(100)	1	9	8	13	3	34

Source: NOAA, 1990.

Considering pollutant sources within EDAs, Table 5–2 shows that agriculture was a minor contributor in three regions — the North and Middle Atlantic and the North Pacific — regardless of pollutant type. Furthermore, agriculture was not a major source of phosphorus runoff. In four regions — South Atlantic, East and West Gulf of Mexico, and the South Pacific — agricultural sources account for 30 to 50 percent of nitrogen and wastewater or surface runoff.

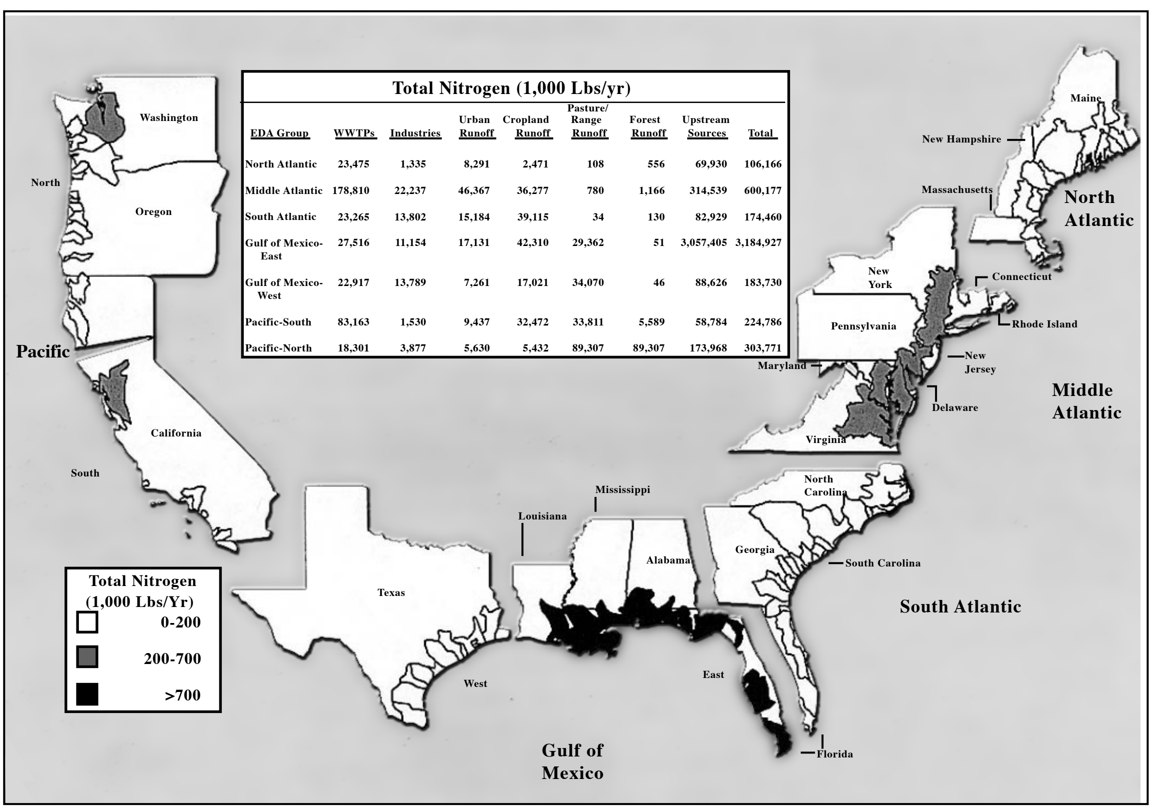
Wetlands

Wetlands are areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions.

Most U.S. wetlands are inland (92 percent in 1982; the remainder are coastal). Coastal marshes and estuaries serve not only as fishing grounds but also as nurseries for fishery resources. Somewhat more than half of U.S. fishery harvests depend on estuarine habitat. The percentage is considerably higher in the Gulf of Mexico.

Threatened and endangered species are frequently associated with wetlands — specifically, 48 percent of the 809 species on the 1993 Federal list (available from BioData, Inc., Golden, Colorado). Fishes and other

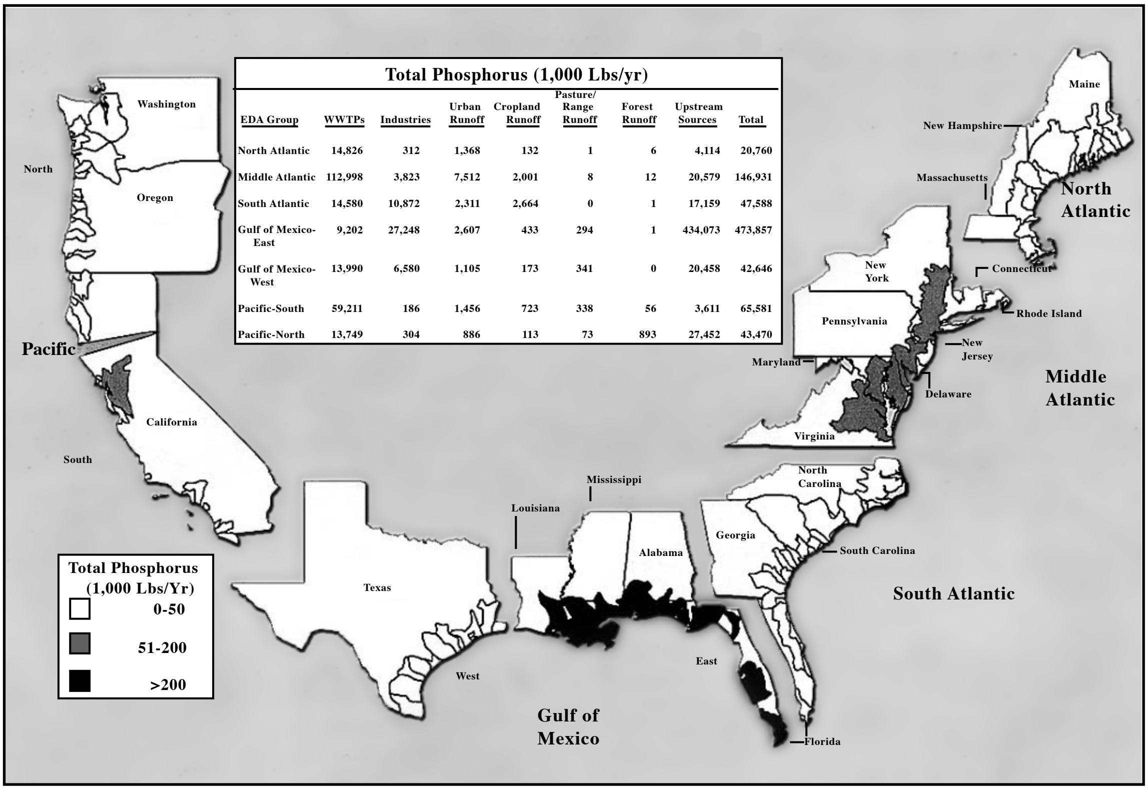
Figure 5-12 Nitrogen runoff estimates in coastal regions by major source category, selected years 1982 to 1987 (NOAA., 1994)



Total Nitrogen (1,000 Lbs/yr)

EDA Group	WWTPs	Industries	Urban Runoff	Cropland Runoff	Pasture/ Range Runoff	Forest Runoff	Upstream Sources	Total
North Atlantic	23,475	1,335	8,291	2,471	108	556	69,930	106,166
Middle Atlantic	178,810	22,237	46,367	36,277	780	1,166	314,539	600,177
South Atlantic	23,265	13,802	15,184	39,115	34	130	82,929	174,460
Gulf of Mexico-East	27,516	11,154	17,131	42,310	29,362	51	3,057,405	3,184,927
Gulf of Mexico-West	22,917	13,789	7,261	17,021	34,070	46	88,626	183,730
Pacific-South	83,163	1,530	9,437	32,472	33,811	5,589	58,784	224,786
Pacific-North	18,301	3,877	5,630	5,432	89,307	89,307	173,968	303,771

Figure 5-13 Phosphorus runoff estimates in coastal regions by major source category, selected years 1982 to 1987 (NOAA., 1994)



Total Phosphorus (1,000 Lbs/yr)

EDA Group	WWTPs	Industries	Urban Runoff	Cropland Runoff	Pasture/ Range Runoff	Forest Runoff	Upstream Sources	Total
North Atlantic	14,826	312	1,368	132	1	6	4,114	20,760
Middle Atlantic	112,998	3,823	7,512	2,001	8	12	20,579	146,931
South Atlantic	14,580	10,872	2,311	2,664	0	1	17,159	47,588
Gulf of Mexico-East	9,202	27,248	2,607	433	294	1	434,073	473,857
Gulf of Mexico-West	13,990	6,580	1,105	173	341	0	20,458	42,646
Pacific-South	59,211	186	1,456	723	338	56	3,611	65,581
Pacific-North	13,749	304	886	113	73	893	27,452	43,470

Table 5-2 Relative importance of agricultural runoff sources of wastewater/surface runoff, nitrogen, and phosphorus within estuarine drainage areas of coastal regions, various years 1982 to 1987

Coastal Region		Wastewater Surface Runoff	Nitrogen Runoff	Phosphorus Runoff
		(Runoff from cropland, pasture, and range as percent of total runoff)		
North Atlantic EDAs		10.2	5.9	6.9
Middle Atlantic EDAs		9.4	12.9	7.5
South Atlantic EDAs		33.6	42.9	15.8
Gulf of Mexico	east EDAs	47.8	55.5	7.5
	west EDAs	50.0	53.9	5.7
Pacific	south EDAs	30.5	39.8	3.4
	north EDAs	8.3	9.2	6.3

Source: NOAA/SEAD for the 3rd RCA

Note: Total runoff generated within the EDAs includes runoff from the three agricultural sources and runoff from wastewater treatment plants, industries, urban areas, and forest land. Because estimates were developed for different years and hence different weather and economic activity for each region, the reader should draw only very limited comparisons between regions.

aquatic fauna are disproportionately imperiled, compared to terrestrial fauna. Imperilment is most acute in areas of high diversity, endemicity, or both — primarily in the southern and western States.

NRI estimates of wetland loss indicate that net nonfederal wetland area declined by 792,600 acres from 1982 to 1992. This net change represents wetland gains in some areas of 769,000 acres and losses in other areas of 1,561,000 acres (Brady 1997). Analysis by Brady and Flather indicates extensive degradation of coastal wetlands by conversion to open water. Some 279,000 acres of coastal fresh marsh and irregularly flooded salt marsh present in 1982 were converted to salt meadow, regularly flooded salt marsh, or estuary by 1987. Salt water intrusion into fresh marshes results in loss of freshwater vegetation and a shift to brackish or salt marsh or to open water. Soil may erode as vegetation is lost and subsidence may occur.

Wetland losses from agriculture have declined from 87 percent of the total loss during the mid-1950s to mid-1960s, to 54 percent during the period of the mid-1970s to mid-1980s, to 20 percent of the total during 1982 to 1992. Reasons for the trend include change in commodity prices, reduced area of wetlands where drainage is economically feasible, and society's increased recognition of the value of wetlands.

The wetlands conservation provision (Swampbuster) of the 1985 and 1990 Farm Bills requires all agricultural producers to protect the wetlands on the farms they own or operate if they want to be eligible for USDA farm program benefits. Section 404 of the Clean Water Act requires a landowner to obtain a permit from the U.S. Army Corps of Engineers prior to beginning any nonexempt activity involving the placement of dredged or fill material in wetlands. Certain ongoing, normal farming practices in wetlands are exempt and do not require a permit.

High water quality is essential for survival, growth, reproduction, and migration of aquatic and riparian communities. Desirable conditions include an abundance of cool oxygenated water throughout the year that is free of excessive amounts of suspended sediments and other pollutants (Brady, 1997).

Water pollutants associated with agriculture — erosion, sedimentation, and pesticides — are among the threats to survival cited in the Federal endangered species list. These three contaminants endanger 21, 14, and 12 percent, respectively, of the 809 species on the list. More generally, agricultural development and grazing endanger 39 and 26 percent of the species, respectively. Note, however, that being listed does not rank the significance of these factors.

Chesapeake Bay

The Chesapeake Bay, the Nation's largest estuary – 64,000 square miles – is home to 13 million people. The initial Bay Agreement – signed in 1983 between Pennsylvania, Maryland, the District of Columbia, Virginia and the Bay Commission – and subsequent amendments in 1987 and 1992 seek to reduce the amount of nutrients reaching the Bay by 40 percent by the year 2000 (Chesapeake Bay Prog. 1992/93 and 1993).

Since 1984, the Bay has been under an intensive monitoring program. Bay Commission annual reports show the following results of conservation activity from 1984 to 1992:

- Submerged aquatic vegetation (SAV) acreage has increased over 75 percent, a significant reversal of the dramatic declines of the mid-1970s. SAV has become the most significant indicator of Bay health.

- Phosphorus concentrations fell 16 percent in the Bay's main stem because of a ban on phosphate-containing detergents, improved wastewater treatment, and stricter compliance with discharge permit limits.

- Nitrate concentrations are holding steady, in contrast to an earlier upward trend. Point source discharges continue to rise as population and wastewater flows increase. Further reduction in nutrients will be achieved largely by improving nutrient management and controlling erosion and sediment on farmland.

- Higher levels of dissolved oxygen have not been documented.

In addition to water quality monitoring, the Bay Commission relies on two physical process simulation models to project water quality change.

The Watershed Model simulates runoff, ground water flow, and river flow to estimate nutrient loadings from point and nonpoint sources. Estimates show that implementing nonpoint source controls would result in reductions of 12 and 8 percent, respectively, in controllable nonpoint source nitrogen and phosphorus.

Watershed Model-estimated sources of nutrients:

Source	Phosphorus	Nitrogen
	(percent)	(percent)
Point	33.7	23.1
Nonpoint	60.9	67.7
Atmosphere	5.4	9.2

Farmland is the largest nonpoint source of each nutrient.

The Three-Dimensional Time Variable Model (3-D Model) is used to estimate Bay water quality and water-quality response to change in nutrient inputs for up to a 10-year pattern of tributary river flows. The 3-D Model receives inputs from the Watershed Model and other sources. Among other results, the model projects a 20 to 25 percent increase in dissolved oxygen in response to the 40 percent reduction in nutrients.

Ground water quality

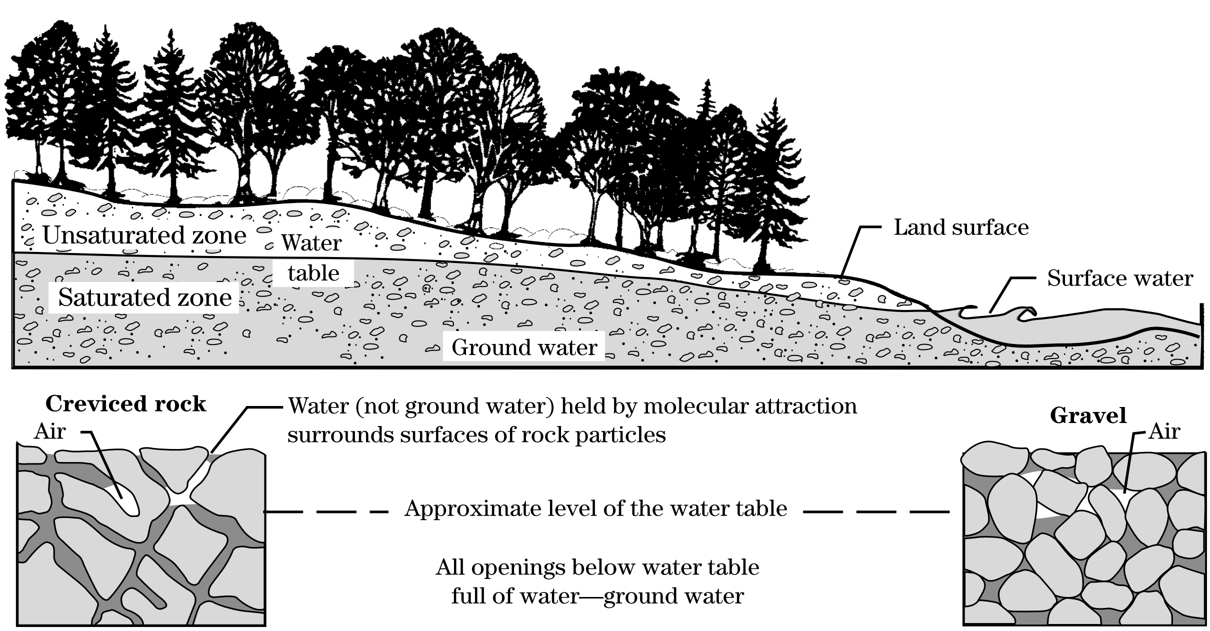
The data problems previously presented for surface water quality are more pervasive and serious for ground water quality. In the EPA *National Water Quality Inventory: 1992 Report to Congress*, State agencies reported that nitrates were found to some extent in the ground water of 49 States; pesticides, in the ground water of 45 States; and other agrichemicals, in the ground water of 23 States. The report did not address the reliability of the data or its relevance to public health. This section will briefly discuss the nature of ground water and published reports of nitrate and pesticides in ground water.

Ground water comes from precipitation that infiltrates into pores or cracks of the earth but does not evaporate or flow overland, is not held by surface water bodies, and has not been transpired by plants (fig. 5–14).

Ground water that does not replace water which has evaporated or that has not been used by plants infiltrates down to the water table. Below the water table is a saturated zone called an aquifer, where openings between rocks are filled with water. This is where most ground water is stored. Perched water tables sometimes exist above the regional water table. They can be locally important sources of ground water. Upper zones of aquifers under or downstream from agricultural areas are most vulnerable to contamination by surface management practices.

Aquifers can be confined or unconfined. A confined aquifer is somewhat separated from the earth's surface by impermeable or slowly permeable layers of materials that restrict upward or downward flows of ground water. This type of aquifer, nevertheless, has recharge zones and return flow areas where it connects to the earth's surface. An unconfined aquifer is not overlain by an impermeable layer and is more readily in contact with the land surface. Aquifers may be shallow,

Figure 5-14 Ground water in the landscape (USGS, 1986)



located only a few feet below the land's surface; they recharge quickly, and fluctuate up and down with changes in streamflow or precipitation. Other aquifers may be thousands of feet deep and recharge only slowly (USGS 1986). Wetlands are areas where ground water aquifers actually intersect the earth's surface (Walker, 1995).

Between the top of an aquifer — the water table — and the land surface is an unsaturated zone called the vadose zone where openings between rocks are smaller and a small amount of water is stored. In a very simple system, water and water-soluble pollutants percolate below the plant root zone and through the intermediate vadose zone to an aquifer.

Because of percolation from the earth's surface and because ground water moves horizontally to wells, streams, and springs, ground water and surface water are interconnected. The pathways of this interconnection are complex and difficult to quantify.

Some 492 billion gallons of ground water, an amount equivalent to about 40 percent of streamflow nationally, is naturally discharged to surface water each day. This water maintains streamflow in low-flow and drought conditions (Job, 1995). Ground water can rejoin the earth's surface downslope and adjacent to a stream, often along a riparian zone. In a riparian zone, the water table moves progressively toward the land surface, and the intermediate vadose zone is lost as the stream channel is approached. During storms or wet periods, the water table can rise rapidly to intersect the land surface some distance from the stream.

Estuaries and all coastal water are strongly influenced by ground water. For example, some 50 percent of the Chesapeake Bay's fresh water and 30 to 40 percent of nitrates entering the bay come from ground water discharge. Ground water can also be contaminated by flooding rivers. USGS, for example, is studying the degree to which, during the 1993 floods, agrichemicals that washed into rivers in the Mississippi River Basin may have leached into ground water.

In 1990, ground water withdrawals provided for over 20 percent of fresh water withdrawn from the natural system for off-stream site uses in the United States (Walker, 1995). It accounted for 51 percent of all drinking water in the United States and 96 percent of the water used in rural areas, including that drawn from private wells. Ground water is continuing to increase as a drinking water source: between 1980 and 1990, two-thirds of new public water supplies came from ground water. The data do not reveal how much ground water is consumed compared to surface water consumption.

Irrigation, which uses the largest amount of water nationally, receives much of its water supply from ground water sources. This amount has decreased from 60 billion gallons per day (bgd) in 1980 to 51 bgd in 1990 (Job, 1995). The largest contributors to the decline were the North Central, Central, and Southwest regions.

Monitoring issues

Monitoring ground water quality is very difficult. State ground water monitoring programs are unique to the history and needs of each State. States, and even agencies within a single State, differ significantly in their objectives for collecting ground water data, parameters identified for measurement, data collection and analysis methods, quality assurance and quality control (QA/QC) procedures, and data storage and accessibility.

States have two major types of monitoring programs: ambient monitoring and federally mandated compliance-based monitoring. Ambient monitoring is practiced in 18 States; 24 States do compliance-based monitoring (Job, 1995). Ambient monitoring typically measures background or existing water quality. In general, compliance-based programs have a large number of sampling points that focus on small areas for specific parameters. Ambient programs are generally more statewide but have fewer points. The design and content of State programs vary greatly.

Monitoring programs have two major types of water quality indicators: constituent-based, such as nitrate concentration; and administrative-based, such as permits issued. Constituent-based monitoring is most relevant for establishing water quality status and trends. Unfortunately, only six States use constituent-based indicators; 10 use administrative indicators; and six use both types. Eight States have done little or no monitoring.

Although the Nation has, therefore, a huge amount of ground water data, it has very limited nationally consistent and reliable data on ground water quality.

EPA's *Pesticides in Ground Water Data Base: A Compilation of Monitoring Studies — 1971–1991* illustrates aspects of the data problem for national and regional status and trends analysis. The database represents information from over 68,000 wells in 45 States.

- The database is not a complete dataset of all U.S. ground water monitoring for pesticides. Several States did not provide data to EPA, even though data were available.
- Monitoring procedures and intensity varied across States. Because some monitoring was initiated in response to suspected problems at local sites within a State, results could not be reliably extrapolated to larger regions.
- Major change in analytical methods and limits of detection over the 20-year period and from laboratory to laboratory makes it hazardous to compare results across studies.
- Although differences in well construction, depth, location, and intended use determine whether a well will be contaminated by pesticides, such well characteristics were not part of the database.

Identifying and quantifying threats to ground water is, and will continue to be, very difficult. Thus, the National Research Council (1993) concluded that the key to protecting ground water rests on assessing its "vulnerability" to contamination and then limiting the potential entry of contaminants applied on or near the earth's surface. Even though determining the degree of vulnerability is such an uncertain process, "an uncertain assessment is better than no assessment at all" (EESI, 1994). Assessments are least accurate where vulnerability appears to be unlikely; for example, the possibility exists that unknown factors such as natural faults or unplugged wells will penetrate protective layers (clay or rock). Designing protective measures can be complex and difficult for several reasons. Contaminants can come from a wide range of point and nonpoint sources; they are also at varying distances from the ground water and may take circuitous paths that are difficult to track.

Pesticides in ground water

EPA began to emphasize ground water monitoring for pesticides in 1979 following discovery of DBCP and aldicarb in ground water in several States. In 1985, 38 States reported that agricultural activity was a known or suspected source of ground water contamination within their borders (ASIWPCA, 1985). Results published from monitoring and analysis since 1985 show that agricultural chemicals are sometimes found in ground water at levels exceeding EPA water quality regulations.

EPA reported in 1988 that 46 pesticides were detected in the ground water of 26 States as a result of normal field operations. Eighteen were found at levels higher than Health Advisory Levels (HALs) though seven of these pesticides had already been severely restricted or canceled.

Results from USGS's ground water study on the Delmarva Peninsula indicated that pesticides were found in shallow wells near the water table. The herbicides atrazine and alachlor were detected most frequently. At a detection limit of 0.13 ppb, about 5 percent of the samples contained atrazine. Atrazine exceeded the Maximum Containment Level (MCL) of 3 ppb in only one sample. MCLs for herbicides are based on average concentrations in a minimum of four quarterly samples, not on individual sample results. The only insecticide detected was carbofuran, and it was found in only two samples. Water samples were tested for 40 of the most commonly used pesticides. Water samples containing pesticides were generally collected at no more than 20 feet below the water table and were near corn or soybean fields. Only a few detections were more than 50 feet below the water table (Hamilton and Shedlock, 1992).

In 1988 to 1989, Monsanto tested for alachlor, atrazine, metolachlor, cyanazine, simazine and nitrate in 1,430 wells in 26 States. In all, 13 percent of the wells had detectable levels of one or more of these herbicides, but less than 1 percent exceeded EPA standards for drinking water (Monsanto, 1990).

On the basis of a national well water survey conducted in 1988 to 1990, EPA estimates that about 10 percent of U.S. community water system wells and about 4 percent of United States rural domestic wells contain at least one pesticide. No community water system wells and less than 1 percent of the rural domestic wells have pesticide levels above the HAL or MCL (EPA, 1990c).

USGS sampled wells from near-surface aquifers (less than 50 feet in depth) in an area of intense row-crop agriculture in the Midwest and found that atrazine (or its metabolites) occurred in 22 percent of the wells. The minimum level of detection was about half that of the EPA 1988 to 1990 survey, which is one reason for the higher incidence of occurrence in the USGS study. The second most frequently occurring pesticide was prometon (5.0 percent occurrence), which is believed to have originated from nonagricultural sources. Of the 11 commonly used herbicides tested, four did not occur in any of the samples. All concentrations found were below the MCL (Kolpin, Burkart, and Thurman, 1994).

Baker, Wallrabenstein and Richards (in press) tested private wells in 17 States and found that triazine herbicides occurred in 9.8 percent of 14,044 samples. However, only 0.4 percent of the samples containing triazine exceeded its MCL (3 ppb) and only 1.5 percent of the samples containing metolachlor exceeded its MCL (2 ppb). All other pesticides tested well within the MCL.

USGS reviewed published information on pesticide detection and behavior in ground water throughout the United States and concluded that we have insufficient information to provide decision makers with a comprehensive view of the occurrence of pesticides in ground water (Leahy, 1995). Generally, the literature showed that pesticides were commonly present at low levels in ground beneath agricultural land. However, almost no information is available on the occurrence of pesticides beneath nonagricultural land, despite significant nonagricultural uses of pesticides.

Nitrate in ground water

USGS compiled historical data on nitrogen and phosphorus concentrations in ground water from some 12,000 samples in 18 of the first 20 NAWQA study units and five supplemental study areas (Mueller et al. 1995). Because the range of conditions in these 20 large areas (fig. 5–15) is sufficiently diverse, the authors deem their findings to warrant national consideration concerning the quality of ground water relative to select pollutants. However, the data is insufficient to discern national or regional trends.

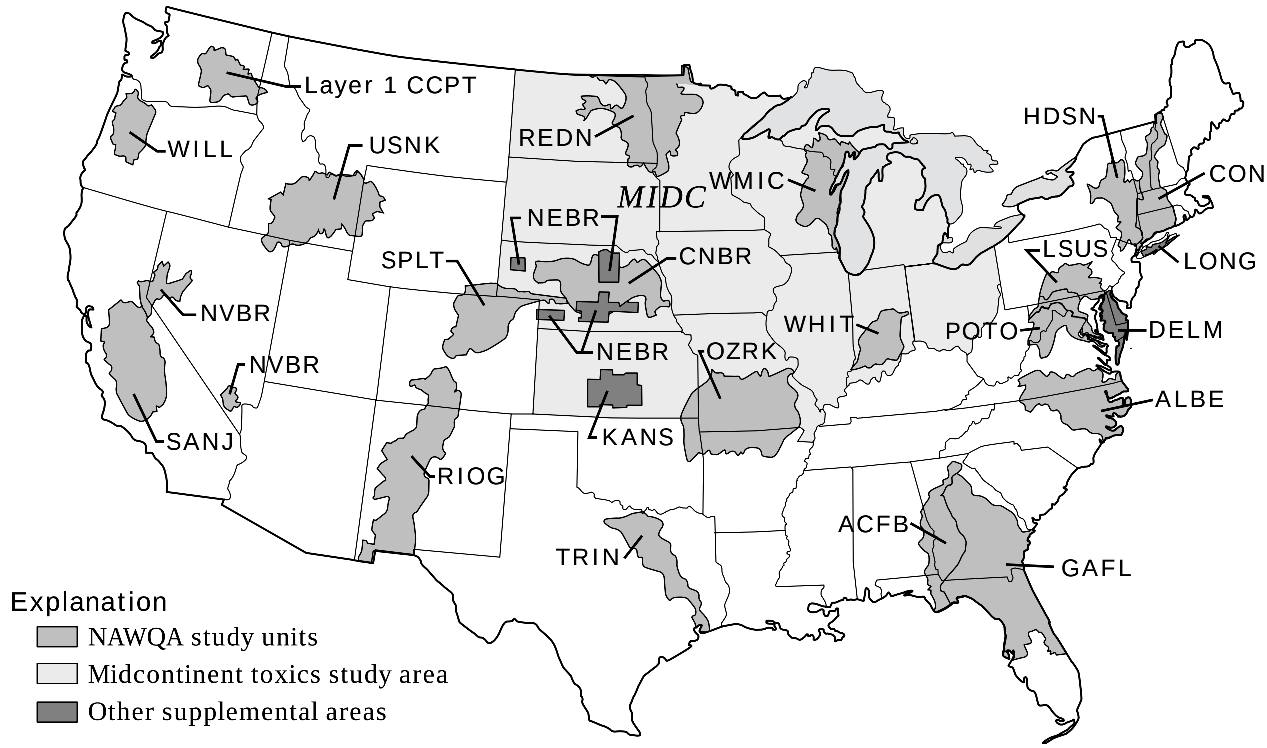
Nitrate is the only nutrient for which EPA has established a maximum contaminant level in drinking water (10 mg/L). The only significant form of dissolved phosphorus in natural water is phosphate; relative to nitrate, however, phosphates are not very mobile in soils and water. No national criteria have been established for phosphorus concentrations in water, but to control eutrophication, EPA recommends that total phosphates should not exceed (a) 0.05 mg/L (as P) in a stream entering a lake or reservoir; or (b) 0.1 mg/L in flowing water not directly discharging into lakes or reservoirs (Mueller et al. 1995).

Data analysis indicated a median nitrate concentration of 0.58 mg/L, a level much below the 10 mg/L maximum contaminant level. Median concentration of total phosphorus was 0.05 mg/L. Median nitrate concentration was lowest in samples collected from public water supply wells and highest in irrigation and stock water samples (table 5–3). Concentrations exceeded the drinking water MCL in approximately 1 percent of the public water supply wells and in 9 percent of the domestic supply wells. Some reasons for these findings, consistent with earlier studies, are that public-supply wells typically penetrate deeper into the ground water system where contaminants are not as prevalent; domestic wells, on the other hand, can be located in rural areas close to septic systems, animal feedlots, and cropland. The highest nitrate concentration was found in samples taken from irrigation and stock water wells.

Factors that affect nitrate concentration in ground water include depth below land surface, hydrogeologic setting, soil hydrologic group, depth to water, land use, and type of agriculture (Mueller et al. 1995). Analyses suggest that concentrations

- decrease quickly to depths of about 150 feet and then decrease more slowly;
- are highest in unconsolidated sand and gravel aquifers — the most permeable hydrogeologic type — and lowest in less permeable bedrock;

Figure 5-15 Initial 20 study units of the U.S. Geological Survey NAWQA Program and five supplemental areas used to assess nutrients in ground water (Mueller et al. 1995)



NAWQA Study Units

Map acronym	Short name in text
ABBE	Albemarle-Pamlico
ACFB	Apalachicola
CNBR	Central Nebraska
CONN	Connecticut
GAFL	Georgia-Florida
HDSN	Hudson
LSUS	Lower Susquehanna
NVBR`	Nevada
OZRK	Ozark
POTO	Potomac

Map acronym	Short name in text
REDN	Red
RIOG	Rio Grande
SANJ	San Joaquin
SPLT	South Platte
TRIN	Trinity
USNK	Upper Snake
WMIC	W. Lake Michigan
WHIT	White
WILL	Willamette

Supplemental Study Areas

Map acronym	Short name in text
DELM	Delmarva
KANS	Kansas Toxics
LONG	Long Island Toxics
MIDC	Midcontinent Toxics
NEBR	Nebraska Toxics

Table 5-3 Nitrate concentrations in ground water by well type for data used in the national analysis

Well type	Median concentration	Median concentrations exceeding drinking-water MCL
Public water supply	0.2 mg/L	1.0%
Domestic water supply	1.3 mg/L	9.0%
Irrigation and stock water	2.4 mg/L	15.6%

Source: Mueller et al. 1995

Maximum contaminant level for drinking water= 10 mg/L

- are highest beneath well-drained soil hydrologic groups and lowest in the hydrologic groups that commonly contain less permeable fine-grained material; and

- are higher in areas with moderate distances between the earth's surface and ground water as compared to areas with longer distances.

Nitrate concentrations beneath agricultural land were significantly higher than in other land uses (table 5–4). Only wells less than 100 feet below the earth's surface were sampled so that results would reflect human activity. Within agricultural land use, concentrations were higher beneath cropland than below pasture or woodland. Below agricultural land, one-fifth of the median nitrate concentrations in ground water exceeded the MCL for drinking water. Pasture and woodland generally receive less fertilizer application, including manures, than cropland.

Just as factors affecting ground water quality differ across the Nation, so, the analysis suggests, do broad

Table 5-4 Nitrate concentrations in ground water by land use for data used in the national analysis

Land use type	Median concentration	Median concentrations exceeding drinking-water MCL
Forest land	0.1 mg/L	3.0%
Range land	1.5 mg/L	8.5%
Agricultural land	3.4 mg/L	21.1%
Urban land	1.9 mg/L	7.0%

Source: Mueller et al. 1995
Maximum contaminant level for drinking water= 10 mg/L

Table 5-5 Summary of nitrate concentrations in ground water below agricultural land, by region

Region[1,2]	Median nitrate concentration	Samples with concentrations > 3 mg/L[3]	Samples with concentrations > 10 mg/L[4]
	(mg/L)	(percent)	(percent)
Northeastern states	4.3	58.2	19.6
Appalachian and Southeastern states	0.2	16.3	2.0
Corn Belt states	0.2	22.6	1.5
Lake states	0.1	25.5	14.6
Northern Plains states	6.0	60.6	35.2
Southern Plains states		(numbers requested)	
Mountain states	0.7	24.9	8.1
Pacific states	5.5	75.0	26.9

Source: Mueller et al. 1995
1 Only includes wells less than 100 feet below the earth's surface.
2 Only 17 of the 20 study units fit easily into the regional classification. Regions are based on R.F. Spalding and Exner, 1991, *Nitrate contamination in the contiguous United States*, Berlin, Springer-Verlag, NATO ASI Series, Vol. G 30, P. 12-48. The eight regions correspond to the 10 USDA Farm Production Regions, except that three USDA regions (Delta, Appalachian, and Southeast) are combined.
3 May indicate elevated concentration resulting from human activities.
4 Maximum contaminate level for drinking water.

regional patterns in quality (table 5–5). Regional nitrate concentrations were significantly higher in samples from the Northeast, Northern Plains, and Pacific States than from other regions. These findings are consistent with regional characteristics:

1. In the northeastern region, agriculture is primarily row crops, manure is frequently used as fertilizer, the proportion of pasture to agricultural land is quite low, and much agricultural land is underlain by permeable material (Mueller et al. 1995).

2. In both the Northern Plains and Pacific States, agriculture is intensive row crop farming, soils are generally well drained and permeable, much land is underlain by material such as sand and gravel that readily allows water to move downward, inorganic fertilizer application rates are particularly heavy, and much cropland is irrigated. The relative frequency of occurrence of nitrate concentrations above 10 mg/L in the Northern Plains is probably skewed by Nebraska where natural background levels of nitrates are high and fertigated (use of irrigation water for applying fertilizer) crops on permeable soils compound the problem. The occurrences of nitrates exceeding MCL would be much less without the background contribution (Walker, 1995). Finally, ratios of pasture and woodland to cropland are very low.

Despite intensive cultivation and fertilizer use, nitrate concentrations in the Corn Belt were among the lowest. This finding is also consistent with previous studies. Soils at the sampling sites were the most poorly drained of any region and contained significant amounts of loess, relatively impermeable fine-grained glacial deposits. For example, in northwestern Ohio, soils are deep and clay-rich, providing a barrier to ground water contamination. Another contributing factor is that the region has a large number of tile drains that intercept leachates on their way to ground water and discharge them to surface water.

The Appalachian and Southeastern States had the lowest nitrate concentrations of all regions, in spite of extensive fertilizer use and well-drained, sandy soils (Mueller et al. 1995). Concentrations may be low because of denitrification in a warm, wet, carbon-rich environment. In addition, the woodland to cropland ratio is significantly higher here than in any other region; forested buffer strips between agricultural fields are widespread.

Lake States' nitrate concentrations were low, possibly because the data collected were from areas with poorly drained soils. Low concentrations in the Mountain States are consistent with a land use pattern in which pasture, range, and forest are widespread and only 3 percent of the region is cultivated.

In summary, nitrate concentrations in ground water were high primarily in cropland areas where ground water was less than 100 feet below the surface and soil and geologic characteristics promoted rapid movement to the aquifer. Concentrations exceeded the MCL in about one-fifth of the wells that tap the upper 100 feet below the land surface. Nitrate is not a health risk for those who drink water from deeper confined and bedrock aquifers, commonly the source for public-supply systems. It poses more of a risk in rural domestic-supply wells that draw from shallow sources in agricultural areas.

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Chapter 6 Water Quality through Agricultural Policies and Programs

Water quality laws and policies reflect societal attitudes and concerns. Over the past decade, societal concern for the environment has prompted the United States to pass and implement a series of laws dealing with water quality. These laws, enacted through the early 1990s, have improved and protected water quality to varying degrees. In the near future, societal concern and new congressional legislation may change how these laws, policies, and programs are perceived.

This chapter sets forth key Federal policies and programs dealing with agricultural sources of water pollution and some State approaches to managing nonpoint source pollution. These policies and programs have had a role in changing water quality over the past 10 years. They have also influenced our perceptions about water quality and change. The USDA (1993a) is a major source for material in this chapter.

Current USDA programs

USDA's water quality initiative

In July 1989, USDA began its Water Quality Initiative (WQI) to promote both traditional and new land treatment and agrichemical management practices that would reduce pollutant loadings to ground and surface water (U.S. Dep. Agric. 1993b). The USDA Working Group on Water Quality, the responsible entity, organized into three committees.

The Educational, Technical, and Financial Assistance Committee helps farmers and ranchers accelerate their adoption of pollution control practices. It supports multiple projects of three major types:

1. Demonstration Projects (DEMOs). In 16 on-farm projects, USDA staff demonstrate innovative practices for four or more years; producers may then adopt these techniques on their own operations.

2. Hydrologic Unit Areas (HUAs). In 74 projects, USDA staff promote producer adoption of traditional practices for four or more years; these projects are located in areas the State identifies as having critical nonpoint source water pollution problems.

3. Water Quality Special Projects. These mostly one-year projects direct nearly all funds to financial assistance (95 percent), with relatively little to no technical assistance.

In addition to its sponsorship of these projects, the committee evaluated DEMOs and HUAs to determine

1. The critical role played by organized collaboration among public and private groups to achieve project objectives (Rockwell et al. 1991).

2. The relative importance of factors that cause producers to change management and land treatment to reduce agricultural water pollution (Nowak and O'Keefe, 1992).

3. The physical impacts that the projects have and are projected to have on water quality (Sutton et al. 1993).

The Research and Development Committee focuses on new and improved practices and production systems. It focuses on the Management System Evaluation Areas (MSEAs) in five selected regions of Iowa, Minnesota, Missouri, Nebraska, and Ohio. MSEAs evaluate alternative corn and soybean production systems under different soil, weather, and hydrologic settings to demonstrate their environmental and economical strengths.

The Database Development and Evaluation Committee assesses the implications of practices and systems on water quality. ERS and the National Agricultural Statistics Service fund and carry out, respectively, farm level surveys to assess alternatives for farmers and other affected parties. Data being collected include types of irrigation, cropping, and production practices; and types, application, timing, and amounts of fertilizer, pesticides, and other chemicals being used. Agricultural surveys are underway in eight critical water quality areas that USGS is also studying in detail.

The 1985 and 1990 Farm Bills

The conservation provisions of the 1985 and 1990 Farm Bills have had a direct effect on erosion, sediment production, and the use of agrichemicals since the mid-1980s:

The CRP, established in the 1985 Farm Bill (the Food Security Act), permits landowners to retire highly erodible or environmentally sensitive cropland from crop production for 10 to 15 years. In 1990, the CRP was modified to target enrollments to water quality, including land in filter strips, other easement practices, and wellhead protection areas. The CRP's overriding objectives (Ribaudo, 1989) are to

- reduce surplus agricultural commodity supplies that lower food and grain prices and increase Federal farm program costs; and

- increase environmental benefits, including improved water quality.

The conservation compliance provision of the Act requires producers with highly erodible land to have an approved conservation plan and to fully implement it by January 1, 1995, to remain eligible for USDA program benefits.

The sodbuster provision — as amended by the 1990 Farm Bill (the Food, Agriculture, Conservation and Trade Act of 1990 [FACTA]) — requires that new conversions of highly erodible land for agricultural production be protected by a fully applied conservation system. The provision applies to highly erodible land that was not under tillage from 1981 to 1985. Producers who fail to comply with the provision may be ineligible for certain USDA program benefits on all land they farm.

The swampbuster provision (also amended by FACTA) discourages wetlands alteration by withholding certain Federal farm program benefits from farmers who convert or modify wetlands. NRCS helps producers identify any part of their land that may be a legal wetland.

The Wetlands Reserve Program (WRP) provides easement payments and cost sharing to farmers who return farmed or converted wetland to a wetland environment permanently or for a long period. Begun as a pilot in FACTA, the first WRP signup included tracts from 265 farms, totaling 49,888 acres. The WRP provides farmers with an option for dealing with hard-to-farm marshy and swampy fields. Landowners from Louisiana and Mississippi accounted for over half the acres in the 1992 pilot program.

Water Quality Incentive projects provide farmers with technical assistance and financial incentives to voluntarily modify their agricultural practices to reduce nonpoint source pollution. The enrollment goal for 1991 to 1995, set forth in FACTA, was 10 million acres.

The Integrated Farm Management Program helps producers adopt farm resource management plans that conserve resources and comply with environmental requirements. Participants enrolled in the Acreage Conservation Reserve (ACR) program may devote at least 20 percent of their enrolled crop-acreage to resource-conserving crops — such as legumes or legume/grass/small grain mixtures — without losing crop-acreage bases or reducing farm program yields.

Unlimited haying or grazing is permitted on up to 50 percent of the resource-conserving crops on ACR lands. Other haying and grazing provisions further increase producer options. The program goal is to enroll 3 to 5 million acres by 1995.

The pesticide recordkeeping provision, which became effective May 10, 1993, requires private applicators of restricted-use pesticides to maintain records accessible to State and Federal agencies. Information includes product identification and the amount, date, and location of each application.

The 1996 Farm Bill

Implementation of provisions of the Federal Agriculture Improvement and Reform Act of 1996 (FAIR) should make significant changes in how USDA provides support to landowners for adopting conservation practices. Some key provisions directly relating to water quality are:

- FAIR combines the functions of the Agricultural Conservation Program, Great Plains Conservation Program, Water Quality Incentives Program, and Colorado River Salinity Control Program into one program — the Environmental Quality Incentives Program (EQIP). EQIP is to provide assistance to farmers and ranchers such that environmental benefits per dollar expended are maximized. EQIP will be targeted to locally identified priority areas where there are water quality and other environmental objectives that may be addressed with agricultural improvements. Eligible land will include cropland, rangeland, pasture, forestland, and other farm or ranch lands in identified priority areas. EQIP contracts will be for 5 to 10 years with possible incentive payments and cost sharing for conservation practices. Funding is authorized at $130 million for FY 1996 and $200 million annually thereafter. At least one-half of the appropriated funding is to be targeted to livestock-related conservation problems.

- The CRP is extended through 2002 with a maximum acreage of 36.4 million acres and with new eligibility criteria to protect the most environmentally sensitive land. The program encourages producers to permanently protect land subject to erosion, to improve soil, water and wildlife resources.

- The Wetlands Reserve Program is extended through 2002 with a maximum acreage of 975,000 acres. Eligibility criteria are broadened to protect environmentally sensitive acres adjacent to wetlands and waterways. Wetlands and swampbuster provisions are modified to provide farmers with more flexibility to meet wetland conservation requirements.

- The Conservation Farm Option (CFO) is a pilot program that will provide producers of wheat, feed grains, cotton, and rice who have a CFO contract the opportunity to consolidate CRP, WRP, and EQIP payments annually, under a 10-year contract, in return for adoption of a conservation farm plan.

Long-standing USDA programs

The Rural Clean Water Program (RCWP), initiated in 1980 and ended in 1995, was an experimental program that addressed agricultural nonpoint-source pollution in 21 U.S. watersheds. The RCWP was administered by the Agricultural Stabilization and Conservation Service in consultation with EPA. Many other USDA agencies, as well as the USGS, participated.

Each RCWP project implemented best management practices (BMPs) to reduce nonpoint-source pollution and monitored water quality to assess physical changes. Critical areas were targeted, landowner participation was voluntary, and cost-sharing and technical assistance were offered as incentives. Five projects received significant additional Federal funds for more extensive monitoring and evaluation. An analysis of project and program findings and recommendations was published in 1993 by EPA.

Colorado River Salinity Program is a voluntary on-farm cooperative USDA and U.S. Department of Interior/Bureau of Reclamation program. Initiated in 1974, it provides cost sharing and technical assistance to farmers to improve the management of irrigated lands and reduce the amount of salt entering the Colorado River. Among its most significant actions were those taken by the Bureau of Reclamation to repurchase highly saline irrigated lands, withdraw other saline lands from early sales, and halt proposal of new construction or completion of irrigation projects in highly saline areas.

Conservation Technical Assistance, initiated in 1936, provides technical assistance to farmers for planning and implementing soil and water conservation and water quality practices. The NRCS and Conservation Districts administer the program.

Agricultural Conservation Program (ACP), initiated in 1936, provides financial assistance to farmers who carry out approved conservation and environmental protection practices on agricultural land and farm-steads. FSA administers the program.

The Small Watershed Program, initiated in 1954 and administered by NRCS, helps local organizations involved in flood prevention, watershed protection, and water management. Part of this effort involves establishing measures to reduce erosion, sedimentation, and runoff. Since the mid-1980s, new project planning has emphasized land treatment measures for watershed protection.

Great Plains Conservation Program (GPCP), initiated in 1957, provides technical and financial assistance in 10 Great Plains States for conservation treatment on entire operating units. Cost sharing is limited to $35,000 per farmer. The GPCP also funds a special water quality project in each of the 10 states.

Resource Conservation and Development Program (RC&D), initiated in 1962 and administered by NRCS, helps county governments enhance conservation, water quality, wildlife habitat, recreation, and rural development in shared resource areas.

The Water Bank Program, initiated in 1970, provides annual rental payments to farmers for preserving wetlands in important migratory waterfowl nesting, breeding, or feeding areas.

The Federal Extension Service, in cooperation with the State Extension Services and State and local offices of USDA agencies and Conservation Districts, provides information and recommendations on soil conservation and water quality practices to landowners and farm operators.

The Farm Service Agency (FSA) provides loans to farmers for soil and water conservation, pollution abatement, and building or improving water systems. The act may acquire 50-year conservation easements to help farmers reduce outstanding loan amounts. FSA also places conservation easements on foreclosed lands or transfers such lands to government agencies for conservation purposes.

Other USDA activities

Agricultural Research Service (ARS) conducts research on new and alternative crops and agricultural technology to reduce agriculture's adverse impacts on soil and water resources.

Cooperative State Research Service (CSRS) coordinates conservation and water quality research conducted by State Agricultural Experiment Stations and land grant universities. CSRS allocates and administers funds appropriated for special and competitive grants for water quality research.

Economic Research Service (ERS) estimates economic impacts of existing and alternative policies, programs, and technology for preserving and improving soil and water quality.

National Agricultural Statistics Service (NASS) collects data on farm chemical use, agricultural practices, costs, and returns.

Forest Service (FS) conducts research on environmental and economic impacts of alternative forest management policies, programs, and practices.

Natural Resources Conservation Service (NRCS) conducts soil surveys, snow surveys, and river basin studies and supports plant materials centers.

Since 1977, NRCS has conducted the National Resources Inventory, which provides updated information on the status, conditions, and trends of land, soil, water, and related resources on non-Federal lands. NRI data, gathered at more than 800,000 locations in 1992, are statistically reliable for national, regional, State, and intrastate analysis.

Other agricultural policies, including a variety of price supports and marketing programs for purposes other than resource protection may also have significant effects on water quality. Under the 1985 Farm Bill (Food Security Act), income supports were determined by the historical acreage base and yield for specific crops, namely, corn, sorghum, barley, oats, wheat, rice, and cotton. This provision links annual payments to the production of a specific crop and may positively influence planting the program crop instead of other, nonprogram crops (McCormick et al. 1990).

Since production practices for program crops are often more erosive and more reliant on agrichemicals than other practices, shifts to program crops can adversely affect ground and surface water quality. Thus, the Food Security Act influences crop rotations and, indirectly, water quality. Suppose, for example, that a farm's historical acreage base for an erosive program crop is large relative to the farm's total acreage. In the interest of maintaining a base — and program payments — the farmer may plant the program crop rather than a crop that is more benign from a water quality perspective; and since rotations are an important component in soil and pest management, maintaining the base can increase the use of commercial fertilizers and pesticides. Substituting commercial chemicals for rotations increases the potential for chemical leaching and runoff (McCormick et al. 1990).

The 1990 Farm Bill (FACTA) added a planting flexibility provision to the Farm Serurity Act under which a producer could plant up to 25 percent of his base acreage in an approved "flex" crop or a different program crop. In 1991, producers took advantage of the provision on 5.7 million acres. A potential 33 million acres could be planted to flex crops (U.S. Dep. Agric. 1991).

Non-USDA Federal programs

Sections 305(b), 314, 319, 320, 402, and 404 of the Clean Water Act are particularly visible sections dealing with water quality.

In 1985, Congress amended the CWA through section 305(b) to stress achieving interim water quality levels, known as "fishable and swimmable" goals. To comply with this section, States biennially report their progress toward these goals to EPA, who then assembles and reports this information to Congress. Chapter 4 provides an overview of this information based on the 305(b) reports from 1992-1993 (U.S. Environ. Prot. Agency, 1995).

The Clean Lakes Program (CWA, section 314) authorizes EPA grants to States for lake classification surveys, diagnostic and feasibility studies, and for projects to implement lake restoration and protection practices.

The Nonpoint Source Program (CWA, section 319) requires States and U.S. Territories to file assessment reports with EPA. These assessments identify navigable waters that cannot attain water quality standards without reducing nonpoint source pollution. States must develop management plans that specify steps to reduce nonpoint source pollution — all States now have EPA-approved programs. The CWA authorizes grants to States of up to $400 million annually to implement these plans; $50 million was awarded in fiscal 1992.

The National Estuary Program (CWA, section 320) is administered by EPA. It helps identify nationally significant estuaries threatened by pollution — 17 programs have been identified. Under the program, conservation and management plans are prepared and Federal grants are available to State, interstate, and regional water pollution control agencies to prepare and implement the plans.

The National Pollutant Discharge Elimination System (NPDES) Permit Program (CWA, section 402) is also administered by EPA. It controls point-source discharges from treatment plants and industrial facilities, including confined animal feeding operations. In 1993, EPA authorized 38 States and one territory to operate the NPDES permit program.

Efforts to reauthorize the Clean Water Act (EESI, 1994) have been meeting controversy in several areas including

- proposals restricting development in, or the enjoyment of, private property rights associated with lands designated as wetlands;
- the merits of risk-adjusted benefit-cost analyses for proposed regulations;
- fiscal impact of Federal regulations on State and local governments;
- the degree to which the CWA fosters regulatory rather than voluntary compliance by those responsible for nonpoint source pollution; and
- the extension of the CWA to ground water.

The Safe Drinking Water Act (SDWA) requires EPA to set standards for drinking water and requirements for water treatment by public water systems. SDWA also requires States to establish a wellhead protection program to protect public water system wells from contamination by chemicals, including pesticides, nutrients, and other agricultural chemicals. EPA may make grants to help States develop and implement safe drinking water and wellhead protection programs.

Pesticide programs, established by the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and administered by EPA, provide the legal basis for pesticide regulation. FIFRA's reregistration process, which requires that EPA approve the active ingredients in all agricultural insecticides and herbicides, could enhance ground water protection by controlling the use of highly leachable chemicals.

The Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) authorizes NOAA and EPA to help States develop Coastal Zone Management Programs and Coastal Nonpoint Pollution Control Programs. Some 29 States now have approved management programs and are developing nonpoint programs for approval. CZARA calls for the use of "technology-based" management measures throughout the coastal zone. A more stringent water quality-based approach could be implemented later to better address known problems. At present, State nonpoint programs must specify enforceable policies and mechanisms to insure that nonpoint source controls conform to EPA guidance.

EPA has developed guidance identifying "the best available, economically achievable" management measures to achieve nonpoint source control. The measures relate to management systems rather than individual best management practices. For agriculture, the measures are sediment/erosion control, animal waste management, nutrient management, pesticide management, livestock grazing, and irrigation.

Coastal zone States must implement the management measures specified in their EPA and NOAA-approved programs by January 1999. Between 1999 and 2001, EPA and NOAA will conduct monitoring to assess effective measures. States will have until 2004 to implement additional measures, where necessary, to attain or maintain water quality standards.

EPA has also begun a Ground Water Quality Protection Program that emphasizes pollution prevention. In 1992, EPA provided $12 million to States to implement comprehensive State Ground Water Protection Programs.

The National Irrigation Water Quality Program, administered by the U.S. Department of Interior, identifies areas affected by toxic elements in irrigation return flows and undertakes remediation in conjunction with other Federal, State, and local agencies and groups.

The National Water Quality Assessment Program (NAWQA), administered by USGS, describes and monitors the status and trends in the Nation's surface and ground water quality, including occurrences of pesticides, nutrients, and sediment.

Regional initiatives include the Chesapeake Bay Program, Great Lakes Program, and Gulf of Mexico Program. Each is a cooperative effort among various States managed by a regional authority. The States contribute funds, and Federal agencies provide assistance. NRCS has accelerated its technical assistance to these programs under the USDA Water Quality Initiative.

State regulations affecting agriculture

State regulations can be specifically designed to protect a water resource, or the resource can be protected under a broad environmental protection statute. In addition, "secondary" statutes may protect water. Few States have comprehensive water quality protection laws.

State water quality regulations affecting farm management are usefully divided into three broad categories: input control, land use controls, and economic incentives. The following examples illustrate the great variety in regulations among the States (Ribaudo and Woo, 1991).

Input controls

Input controls affect the way pesticides, nutrients, or soil can be managed or used.

■ **Pesticides.** Federal control of pesticide registration is through FIFRA; however, States can apply more stringent requirements. Arizona, California, and Wisconsin require strict regulation of pesticides that might potentially enter an aquifer.

Some States have increased the pesticide registration fees paid by manufacturers. In Iowa, a fee based on gross sales can range between $250 and $3,000 for each product and formulation. Registration fees are also high in California, Minnesota, North Carolina, and Wisconsin. States may also place application restrictions on pesticides that go beyond the EPA requirements.

At least six States control chemical application through irrigation. A potential danger is that chemicals can enter the aquifer directly unless the system has a device to prevent backflow.

■ Fertilizers. Although the Federal government does not regulate fertilizers, some 17 States do. State strategies include restricting general use, creating special protection areas, and targeting landowner complaints.

Arizona, for example, places general restrictions on nutrient runoff. Arizona grants farmers a general permit for nitrogen fertilizer application that requires nitrogen best management practices (BMPs). If the State finds that a farmer is not using BMPs, it will revoke the general permit and require an individual permit. An individual permit is more difficult to obtain and invokes severe monetary penalties for farmers in violation.

Iowa imposes surcharges on fertilizer sales. It uses the funds to support the Leopold Center to disseminate information to farmers that may help them reduce their reliance on chemicals.

In Nebraska, Natural Resource Districts (NRD) can establish Special Protection Areas (SPA) for ground water. NRDs develop plans for farmers within SPAs to control, stabilize, reduce, or prevent the increase or spread of ground water contamination. The Central Platte NRD, for example, calls for a ban on all fall and winter nitrogen applications when the average nitrate concentration in monitoring wells is 20.1 mg/L or greater. Farmers failing to comply can be fined or jailed.

Connecticut requires nitrogen BMPs in areas located above stratified drift aquifers to protect drinking water supplies. Michigan requires BMPs for phosphorus reduction in the Saginaw Bay and Lake Erie watersheds.

In at least seven States, landowner complaints can trigger nutrient BMP requirements if a water quality standard is violated.

■ Soil. Among the 19 States requiring soil erosion controls to address water quality problems, eight require erosion control plans on cropland. Ohio, for example, requires that farmers apply and maintain conservation practices to hold sheet and rill erosion and wind erosion at less than permissible soil loss values (T). Idaho requires BMPs in the watersheds of scenic, high quality waters.

At least 10 States require BMPs based on complaints filed by a citizen or government agency. As with nutrient BMPs, most States work with the operator to address the problem and to cost-share the practices. Penalties are a last resort.

Land use controls

Land use controls — including zoning, land acquisition, and easements — are targeted to areas deemed critical for protecting water resources. Most States restrict land use in wellhead protection areas or over sole-source aquifers. In most States, local zoning may be the best hope for ground water protection. However, agriculture is often excluded from any land use controls that protect ground water, mainly because of resistance in rural areas.

In Pennsylvania, agricultural fields must be set back from streams, leaving a vegetative filter strip. Maryland restricts cropping practices within 12,000 feet of the Chesapeake Bay shoreline and adjacent to all tributaries flowing into the Bay.

Economic incentives

States also use cost-sharing and taxes to influence operators to adopt new management practices. Cost-share programs are voluntary and can be effective in the short run.

At least four States tax nitrogen fertilizers, either through fertilizer retailers or directly on the farm. In all cases, however, the tax is intended as a source of revenue. The tax rates are low enough that no discernable reduction in use has been observed.

State management overview

As many as 27 States have laws affecting farm management decisions. However, no State has a comprehensive legal framework to protect both surface and ground water from all agricultural nonpoint source pollutants. Even when a water quality law affects agriculture, the degree to which the law is implemented or enforced differs among States.

States' efforts to develop agricultural nonpoint source management programs are in the early stages. As better monitoring data and chemical fate and transport models are developed, States can develop more comprehensive and enforceable control programs to replace inadequate voluntary programs.

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Acronyms

ARS	Agricultural Research Service
ASCS	Agricultural Stabilization and Conservation Service
BMP	Best Management Practice
CRP	Conservation Reserve Program
CWA	Clean Water Act
CZARA	Coastal Zone Reauthorization Amendment of 1990
DEMOs	water quality demonstration projects
DO	dissolved oxygen
DP	dissolved phosphorus
EPA	U.S. Environmental Protection Agency
EPIC	Erosion Productivity Impact Calculator
ERS	Economic Research Service
ES	Extension Service
ET&FA	Educational, Technical, and Financial Assistance Committee
FACTA	Food, Agriculture, Conservation, and Trade Act of 1990
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FPR	Farm Production Region
FS	Forest Service
FSA	Food Security Act of 1985
GIS	geographical information system
HAL	health advisory level
HEL	highly erodible land
HUA	hydrologic unit area
ITFM	Intergovernmental Task Force on Water Quality Monitoring
MCL	maximum contaminant level
N	nitrogen
NASS	National Agricultural Statistics Service
NAWQA	National Water Quality Assessment
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NRI	National Resources Inventory
P	phosphorus
RCA	Resources Conservation Act of 1977
SDWA	Safe Drinking Water Act
T	soil loss tolerance
TP	total phosphorus
USGS	U.S. Geological Survey
WQI	USDA Water Quality Initiative
WRP	Wetlands Reserve Program

The USDA Reoganization Act of 1994 changes the names and organizational patterns of several USDA agencies referred to in this report:

ASCS is part of the new Farm Service Agency.
ES is part of the new Cooperative State Research, Education and Extension Service.
SCS is now the Natural Resources Conservation Service.