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Anonymous

Nutrients from atmospheric and urban sources, fertilization, and livestock wastes can contribute to excessive algal growth in streams


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Nutrients

Human activities—including agricultural and urban uses of fertilizer, agricultural use of manure, and combustion of fossil fuels—have caused widespread increases of nitrate in shallow ground water and total nitrogen and total phosphorus in streams across the Nation.

Nitrate did not pose a national health risk for residents whose drinking water came from streams or from major aquifers buried relatively deep beneath the land surface. Some concerns were evident in 4 of the 33 major aquifers sampled, where nitrate concentrations in more than 15 percent of each aquifer exceeded the USEPA drinking-water standard. The most prevalent nitrate contamination of ground water, however, was found in relatively shallow ground water in rural areas where the water commonly is used for domestic supply.

In more than one-half of sampled streams, concentrations of total nitrogen and total phosphorus were above national background concentrations. Elevated phosphorus levels, in particular, can lead to excessive plant growth (eutrophication) in freshwater environments; in more than one-half of sampled streams and in three-fourths of agricultural and urban streams, average annual concentrations of total phosphorus exceeded the USEPA desired goal for prevention of nuisance plant growth. The highest total nitrogen and total phosphorus concentrations were found in small streams draining watersheds with large proportions of agricultural or urban land. Long-term monitoring of streams indicates that programs to control point-source discharges of phosphorus and ammonia have been effective, despite population increases in most metropolitan areas. Phosphorus concentrations have decreased as a result of reductions in the use of phosphate detergents and in the amount of phosphorus discharged from upgraded wastewater treatment plants. Improved wastewater treatment, which converts ammonia to nitrate, generally has resulted in a decrease in ammonia concentrations and an increase in nitrate concentrations in streams. Thus, concentrations of total nitrogen downstream from metropolitan areas have changed little during the past 20 years, although toxicity to fish has decreased with decreasing ammonia levels.

Results from NAWQA studies have shown regional and seasonal differences in nutrient concentrations that can be explained largely by the amounts and timing of fertilizer and manure applications and by the variety of soils, geology, climate, and land- and water-management practices across the Nation. Recognition of these differences is important for efficient protection of ground water needed for drinking and for curbing eutrophication of surface water.

WHAT WAS MEASURED…

Nitrate is the primary form of nitrogen dissolved in streams and ground water. In this report, nitrate refers to the sum of nitrate plus nitrite, as reported by the USGS laboratory. Nitrite concentrations commonly were less than the laboratory detection level of 0.01 milligrams per liter (mg/L), making its contribution to nitrate plus nitrite negligible.

Ammonia is a dissolved form of nitrogen that is less common than nitrate. As measured by the USGS laboratory, total ammonia includes ammonium ion and **un-ionized ammonia.** The latter is usually a minor component of ammonia at pHs commonly observed in streams and ground water.

Total nitrogen includes nitrate, nitrite, ammonia, and organic nitrogen. Nitrite is generally unstable in surface water and contributes little to the total nitrogen. Organic nitrogen (mostly from plant material or organic contaminants) can exist in considerable proportions and contribute substantially to total nitrogen in streams.

Phosphates are the most common forms of phosphorus found in natural waters. Compared to nitrate, phosphates dissolve less readily. They are not mobile in soil water and ground water because they tend to attach to soil and aquifer particles. They can have a significant impact, however, because eroded soil can transport considerable amounts of attached phosphates to streams and lakes. **Orthophosphate** typically constitutes the majority of dissolved phosphates, which can be readily assimilated by aquatic plants and promote eutrophication.

Total phosphorus includes phosphates, as well as all other phosphorus forms. Dissolved phosphates and particulate organic phosphorus (mostly from plant material) are the main components of total phosphorus.

For brevity, all forms of nutrients discussed in this report represent concentrations as either nitrogen or phosphorus. For example, a nitrate concentration expressed as 10 mg/L refers to a nitrate concentration of 10 mg/L as nitrogen.

Background concentrations of nutrients are low in streams and ground water

Background concentrations of nutrients were estimated on the basis of samples collected from undeveloped areas considered to be minimally affected by agriculture, urbanization, and associated land uses. Background concentrations in undeveloped areas are controlled primarily by naturally occurring minerals and by biological activity in soil and streambed sediment. Chemical properties of the atmosphere and rainwater, which can reflect human-related fuel combustion and other activities both within and external to a watershed, can increase background concentrations.

In this report, national background nutrient concentrations include atmospheric contributions and are summarized in the following table. **Waters with concentrations of nutrients greater than the national background concentrations are considered to have been affected by human activities in a variety of land-use settings.**

ESTIMATES OF NATIONAL BACKGROUND NUTRIENT CONCENTRATIONS

Nutrient	Background concentration (mg/L)
Total nitrogen in streams [Data from 28 watersheds in first 20 Study Units]	1.0
Nitrate in streams (26)	0.6
Ammonia in streams (26)	0.1
Nitrate in shallow ground water (27)	2.0
Total phosphorus in streams (26)	0.1
Orthophosphate in shallow ground water [Data from 47 wells in first 20 Study Units]	0.02

Background nutrient concentrations can vary considerably from region to region, or even within watersheds, because of differences in hydrology and in naturally occurring nutrient levels in soils, rocks, and the atmosphere. The data analyzed for this report are insufficient to define background nutrient concentrations on a regional basis. Thus, all available data from undeveloped areas were combined to derive national background concentrations. The national background concentrations are higher than most concentrations measured in relatively undeveloped areas across the Nation and may not be applicable for use in regional or local analyses.

Human activities have increased nutrients above background concentrations

Effects of human activities on nutrients were assessed by comparing concentrations in streams and ground water to national background concentrations. Waters with nutrient concentrations above background are referred to as "enriched" in this report. Fifty-seven percent of sampled streams were enriched with total phosphorus on the basis of average annual total phosphorus concentrations exceeding national background concentrations. Similarly, 61 percent of sampled streams were enriched with total nitrogen and nitrate, but only 23 percent of sampled streams were enriched with ammonia. Only 1 of 28 relatively undisturbed forested or rangeland streams had average annual concentrations of total phosphorus or total nitrogen above national background concentrations. Most of the streams that were enriched with nutrients drained areas of agricultural and (or) urban land.

In 53 percent of shallow ground-water studies in agricultural and urban areas, median nitrate concentrations were above the national background concentration. Median nitrate concentrations were above background in only 3 of 33 major aquifers studied. Those three aquifers were beneath agricultural areas in three different Study Units.

In most cases, enrichment of streams with nutrients occurred in small watersheds and (or) regions dominated by agricultural or urban land use. Effects of human activities were found in shallow ground beneath agricultural and urban areas throughout the Nation, but not in many of the major aquifers sampled.

STANDARDS AND GUIDELINES FOR PROTECTING WATER QUALITY

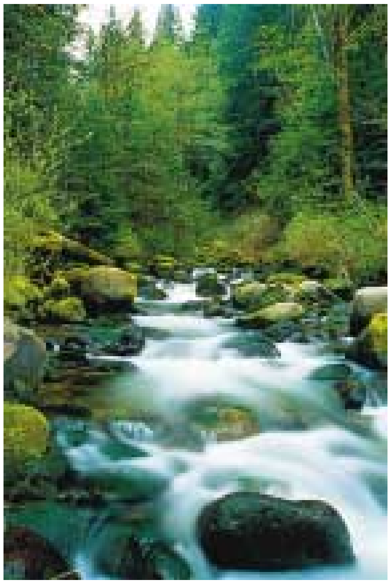
The USEPA has established a Federal drinking-water standard or Maximum Contaminant Level (MCL) of 10 mg/L for **nitrate**.[28] An MCL is a concentration above which adverse human health effects may occur.

The USEPA[29] has established criteria for **un-ionized ammonia** in surface water because of its toxicity to fish. The chronic criteria vary from 0.07 to 2.1 mg/L of total ammonia for pHs of 6.5–9.0 and water temperatures of 0–30 °C.

National criteria have not been established for concentrations of dissolved phosphates in streams or ground water.

National criteria have not been established for total phosphorus or total nitrogen in streams. The USEPA has established a desired goal of 0.1 mg/L **total phosphorus** for the prevention of nuisance plant growth in streams and other flowing waters not discharging directly to lakes or impoundments.[29]

Jeffrey D. Stoner



Dennis A. Wentz

The Otter Tail River, Minnesota (above), which supports a healthy growth of wild rice, and Fir Creek, Oregon (right), which contributes to Portland's drinking-water supply, are examples of streams with low nutrient concentrations.

Nutrients are a potential concern for human health

From a national perspective, nitrate contamination did not pose a health risk for residents who drank water from major aquifers buried relatively deep below land surface. Some concerns were evident, however, in 4 of the 33 major aquifers sampled. In each of these four aquifers, nitrate concentrations in more than 15 percent of samples exceeded the USEPA drinking-water standard. All four aquifers are relatively shallow, in agricultural areas, and composed of sand and gravel that is vulnerable to contamination by land application of fertilizers. In nearly one-half of the major aquifers sampled, water from at least one well, out of 20 to 30 wells, exceeded the drinking-water standard. **Many of the major aquifers exhibiting high nitrate concentrations were used for rural domestic water supply.**

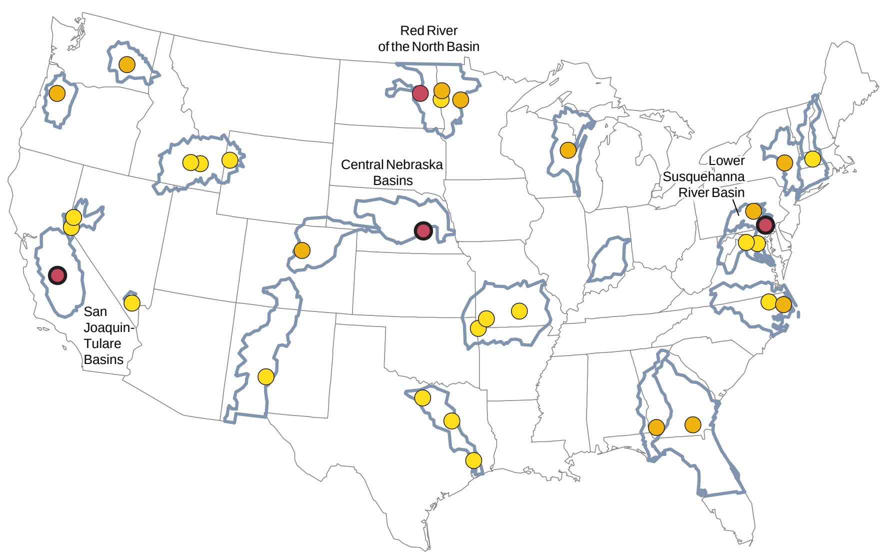
A national ranking of NITRATE concentrations in major aquifers

Percentage of samples exceeding drinking-water standard for nitrate (10 milligrams per liter)—
Each circle represents a major aquifer

- Greater than 15
- Less than 15 (but at least 1 sample)
- 0 samples exceed standard

Background concentration

- Bold outline indicates median values greater than background concentration (2 milligrams per liter)



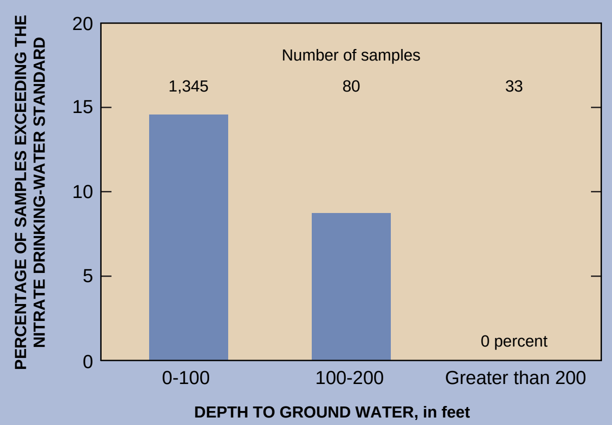
See p. 31 for more information about this map

About 15 percent of all shallow ground water sampled beneath agricultural and urban areas exceeded the drinking-water standard for nitrate. **The presence of elevated nitrate concentrations in shallow ground water raises concerns, particularly where these vulnerable aquifers contain deeper wells used for rural domestic water supply. Contamination of shallow ground water may be a warning to alert populations to potential future risks from consumption of water from deeper wells in these aquifers.**

Because of its proximity to the land surface, shallow ground water is younger and more vulnerable to contamination from human activities than deep ground water. Major aquifers generally are buried deep beneath the land surface, where they are protected by layers of clay or rock that are relatively impermeable and that impede downward movement of water and nitrate. Ground water in major aquifers sampled by the NAWQA Program can be tens to hundreds of years old and, therefore, minimally affected by recent land-use practices.

Geology and hydrology control the movement of contaminated water from shallow to deep systems, and understanding their effects allows an anticipation of possible areas of concern in major aquifers. For example, elevated concentrations of nitrate were detected in a major aquifer in the Lower Susquehanna River Basin (median concentration about 7 mg/L) because karst (weathered carbonate rock) contains open conduits that allow rapid downward movement of water and chemicals. Median concentrations of nitrate also were high in the alluvial aquifer of the Central Nebraska Basins (about 6 mg/L) and in the alluvial fans of the San Joaquin-Tulare Basins (about 5 mg/L). Extensive pumping causes vertical mixing of ground water in these relatively permeable sand and gravel aquifers. In contrast, the median concentration of nitrate was low (0.4 mg/L) in a surficial sand and gravel aquifer in the Red River of the North Basin; however, 15 percent of the samples exceeded the drinking-water standard. This last example demonstrates the complex effects that local geology and nitrate sources can have on nitrate contamination.

For large rivers and most of the smaller streams sampled, nitrate is not a drinking-water issue. This conclusion is based on comparisons of average annual and average monthly concentrations to the drinking-water standard. In only two of all sampled rivers and streams did the average annual concentration of nitrate exceed the drinking-water standard. These two streams drained small agricultural watersheds in the Lower Susquehanna River and Willamette Basins, and neither was used to supply drinking water.



The percentage of ground-water samples with concentrations of nitrate exceeding the drinking-water standard of 10 mg/L decreases as depth to water increases. Mixing of shallow ground water with deeper, uncontaminated water and increased thickness of protective, impermeable geologic materials with depth may help explain this relation.

Kevin F. Dennehy

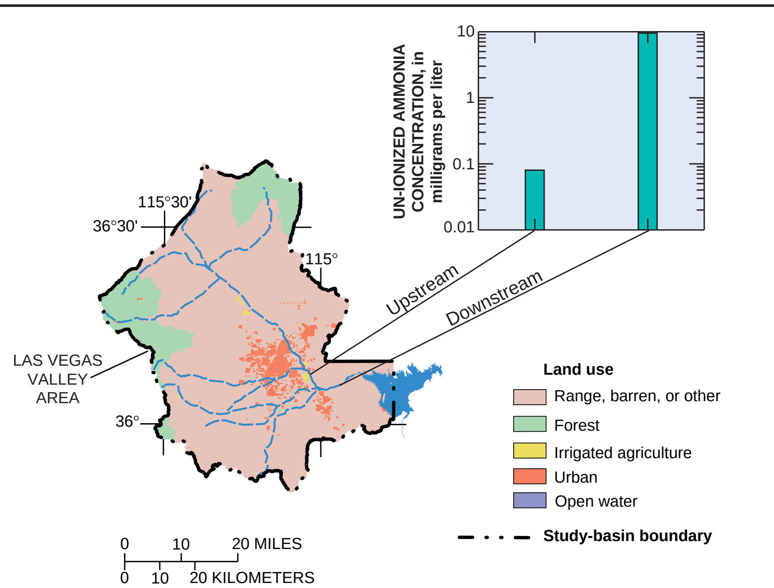
From a national perspective, nitrate did not pose a health risk for residents who drank water from major aquifers buried relatively deep below the land surface. People drinking ground water from shallow wells in vulnerable geologic settings (sand, gravel, or karst) in rural agricultural areas, however, are at risk of exposure to nitrate contamination.

Nutrients are a potential concern for aquatic life

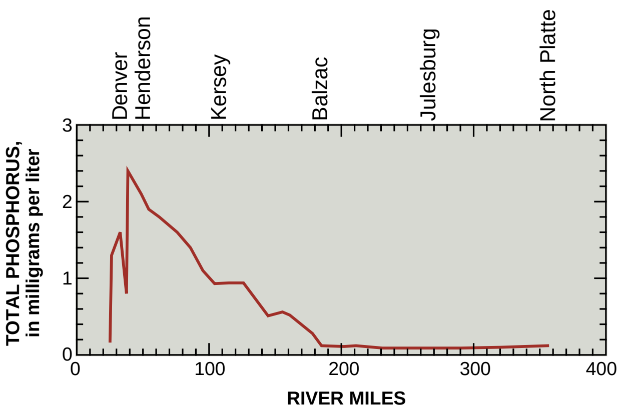
Average annual and average monthly concentrations of un-ionized ammonia did not exceed USEPA aquatic-life criteria for most streams sampled. Exceptions include an agricultural stream affected by upstream wastewater treatment plant effluent in the San Joaquin-Tulare Basins and two urban streams, one in the South Platte River Basin and another in the Nevada Basin and Range. The urban streams, which are in relatively arid climates and exceeded the criteria year-round, also received effluent from wastewater treatment plants.

Eutrophic conditions were noted in some streams across the Nation because of elevated concentrations of nutrients. For example, the average annual concentration of total phosphorus in 57 percent of all streams sampled was greater than the USEPA desired goal of 0.1 mg/L for preventing nuisance plant growth in streams. In addition, about 75 percent of agricultural and urban streams exceeded this goal. **It is difficult and premature, however, to attempt a national summary of eutrophication effects because of limited available methodologies for deriving criteria based only on nutrient concentrations.** Moreover, the uncertainty regarding how nutrient contamination of streams harms aquatic life and affects nuisance plant growth does not lessen the value of accurate information for management of our Nation's streams. A strategy, spearheaded by the USEPA in collaboration with other Federal and State agencies, is underway to evaluate excessive aquatic plant growth, such as algae, in surface water. This strategy includes an understanding of stream nutrient dynamics, stream habitat (including shading and temperature), turbidity, and algal-growth processes.

Nitrogen and phosphorus have different effects on aquatic plant growth in freshwater and saltwater. Eutrophication of freshwater streams generally results from high phosphorus concentrations. In contrast, excess nitrogen, and nitrate in particular, can lead to algal blooms in coastal waters. The USEPA suggests a desired goal of 0.1 mg/L total phosphorus for freshwater streams, but there are no national criteria established for nitrogen concentrations to control excessive aquatic plant growth in coastal bays and estuaries.



Un-ionized ammonia concentrations exceeded USEPA criteria for protection of aquatic life in Las Vegas Wash, Nevada, downstream from wastewater treatment plant discharges. Concentrations in all samples collected from April 1993 to April 1995 exceeded the criteria. The median ammonia concentration downstream from wastewater treatment plant discharges was more than 100 times the median value upstream from the discharges. Downstream ammonia concentrations decreased fivefold during 1996–97, following full implementation of tertiary treatment of wastewater, and USEPA criteria probably are no longer exceeded at this site.



In April 1994, total phosphorus concentrations in the South Platte River exceeded the USEPA desired goal for preventing plant nuisances (0.1 mg/L) in a 150-mile reach downstream from Denver, Colorado.

"As part of the Clean Water Action Plan, the Vice President called upon USEPA to accelerate development of nutrient water-quality criteria for beneficial ecological uses in every geographic region in the country. We will work with States and tribes to develop a methodology for deriving criteria, as well as developing criteria where data are available, for nitrogen and phosphorus runoff for lakes, rivers, and estuaries by the year 2000. We intend to develop such criteria on a regional basis using scientifically defensible data and analysis of nutrients, such as those available from the USGS. We will assist States and tribes in adopting numerical nutrient criteria as water-quality standards by the end of 2003."

Robert Cantilli, Nutrients Criteria Coordinator, USEPA

Large amounts of nitrate enter the Chesapeake Bay from the Susquehanna River. Nitrate concentrations in the Susquehanna River at Harrisburg, Pennsylvania, generally were less than 2 mg/L. However, these concentrations, when multiplied by the large flows of the Susquehanna River, contribute large amounts of nitrate to Chesapeake Bay (especially compared with other rivers entering the bay) and provide enough nitrate to stimulate algal growth and affect the bay ecosystem.

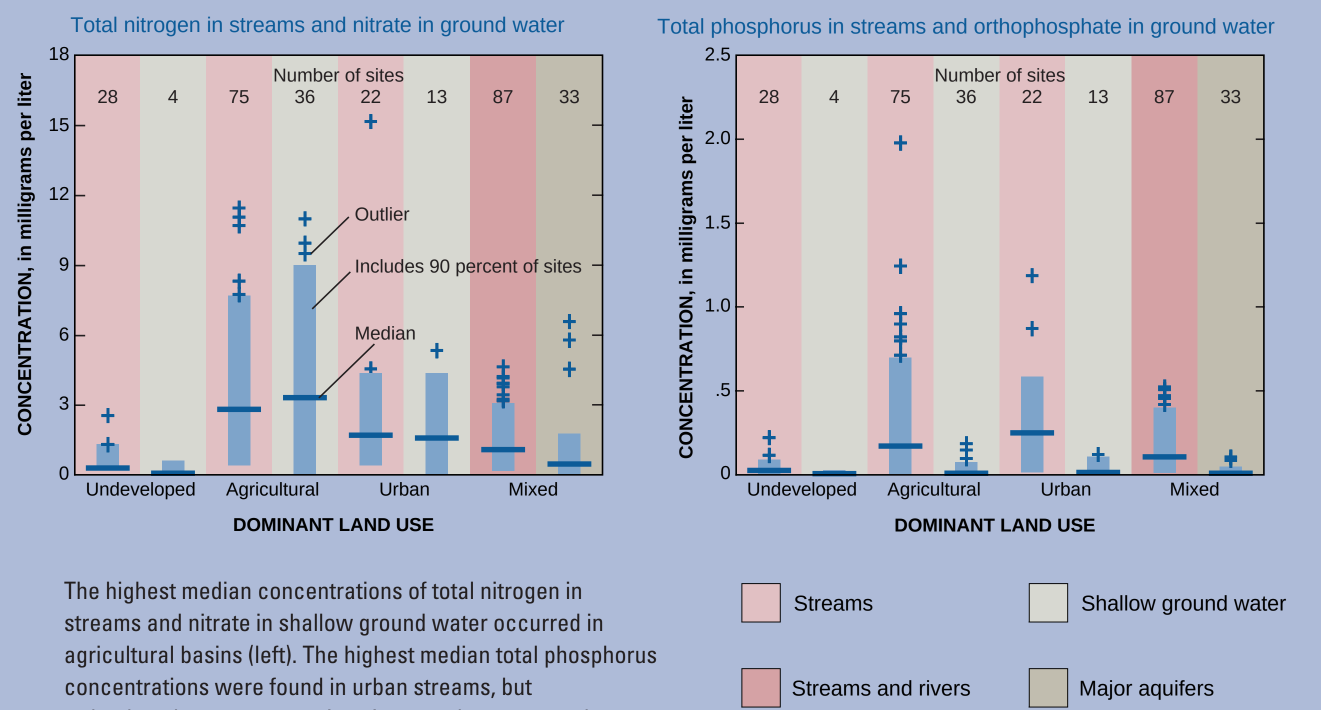
Larry J. Puckett

Nutrient conditions differ by land use

The highest nitrogen and phosphorus concentrations generally were found in agricultural and urban streams. Nutrient concentrations in areas of mixed land use were lower than in agricultural or urban areas but were higher than in undeveloped areas. Orthophosphate concentrations in ground water typically were so low that relations to land use are not definitive.

Except for nitrogen in agricultural areas, nutrient concentrations in streams generally were higher than those in shallow ground water, regardless of land use. In agricultural areas, nitrate concentrations in shallow ground water typically were higher than total nitrogen concentrations in streams, although exceptions occurred in areas where soil characteristics restrict downward movement of water.

Regional patterns in nutrient concentrations can be useful for determining areas of the Nation where environmental settings deserve the greatest concern and attention. The discussion and maps on pages 41–45 focus on geographic patterns in relation to land use and nutrient inputs. Methods used to construct the maps are explained on page 31.



The highest median concentrations of total nitrogen in streams and nitrate in shallow ground water occurred in agricultural basins (left). The highest median total phosphorus concentrations were found in urban streams, but orthophosphate concentrations in ground water were low everywhere (right).

NITRATE IN SHALLOW GROUND WATER

High concentrations of nitrate in shallow ground water were widespread and strongly related to agricultural land use, but there were no apparent regional patterns. Based on comparisons with background concentrations, human activities have increased nitrate concentrations in ground water for about two-thirds of agricultural areas studied, compared to about one-third of urban areas. Median nitrate concentrations for 13 of 36 agricultural areas were greater than 5 mg/L and ranked among the highest of all shallow ground-water studies. Only 1 of 13 urban areas fell into this high-concentration group. It is likely that nitrogen sources in urban areas are relatively localized when compared with the generally more intensive and widespread use of fertilizers on cropland. Also, the impervious surfaces typically found in urban areas generally result in surface runoff of nutrient-laden water, rather than seepage to ground water.

A national ranking of NITRATE concentrations in shallow ground water

Median concentration of nitrate—in milligrams per liter.
Each circle represents a ground-water study

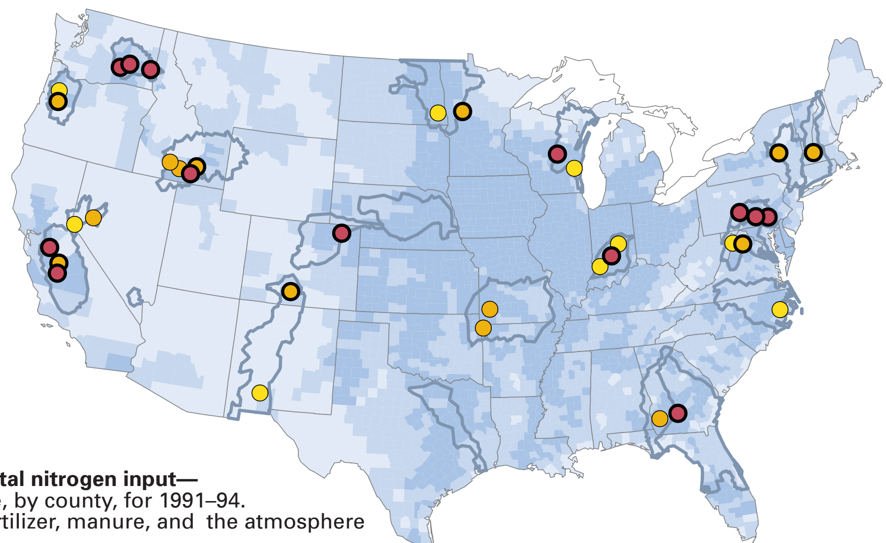
- Highest (greater than 5.0)
- Medium (0.5 to 5.0)
- Lowest (less than 0.5)

Background concentration

- Bold outline indicates median values greater than background concentration (2 milligrams per liter)

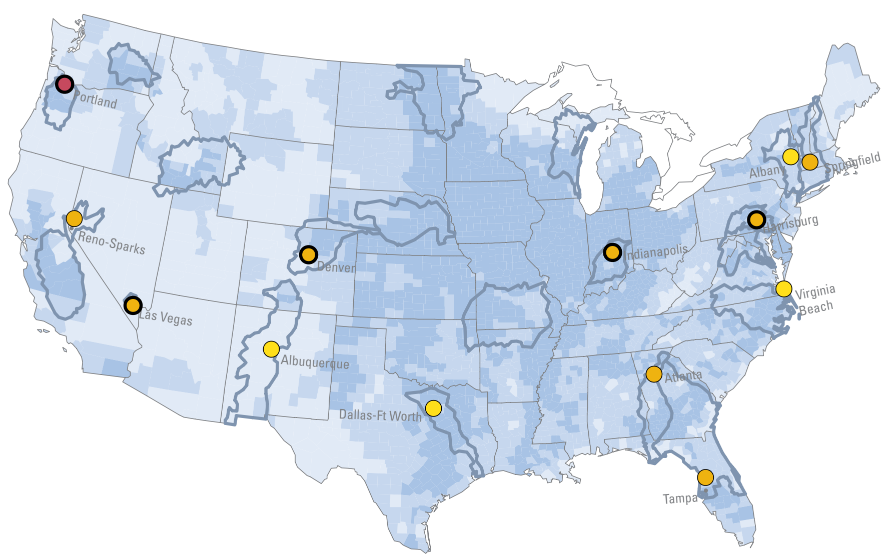
Agricultural areas

Nitrate concentrations in agricultural areas were among the highest measured, but not all agricultural areas had median values above the national background concentration.



Average annual total nitrogen input—
in pounds per acre, by county, for 1991–94.
Inputs are from fertilizer, manure, and the atmosphere

- Highest (greater than 25)
- Medium (6 to 25)
- Lowest (less than 6)



Urban areas

Nitrate concentrations in urban areas generally were lower than in agricultural areas, but 40 percent of urban areas had median values above the national background concentration.

See p. 31 for more information about these maps

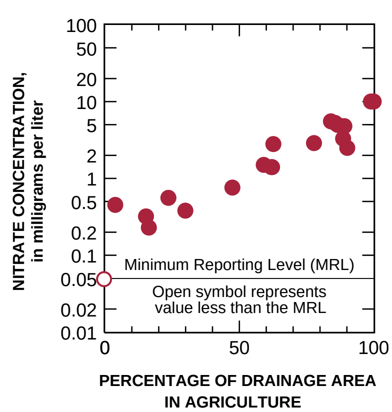
NITROGEN IN STREAMS

Average annual concentrations of total nitrogen in about 50 percent of agricultural streams ranked among the highest of all streams sampled in the first 20 Study Units, and concentrations in about 36 percent of urban streams were among the highest measured. In contrast, total nitrogen levels in streams draining relatively undeveloped, forested watersheds (not shown on the national maps) ranked among the lowest of all streams sampled.

High concentrations of nitrogen in agricultural streams correlated with nitrogen inputs from fertilizers and manure used for crops and from livestock wastes. The Upper Midwest is a notable region of high nitrogen levels in agricultural streams; however, there are also many such examples in the West and East. High nitrogen levels in urban streams probably were related to nitrogen introduced from fertilizers applied to suburban lawns and golf courses, emissions from automobiles and electric powerplants, and effluent from sewage treatment facilities.

Streams and large rivers that drain areas of mixed land use had average annual concentrations of total nitrogen at various levels across the Nation, with no apparent regional pattern. The highest average annual concentrations occurred in watersheds with the highest nitrogen inputs and in rivers downstream from major metropolitan areas. The lowest concentrations in streams draining areas of mixed land use were for watersheds having considerable proportions of forest.

For all streams sampled, the highest concentrations of total nitrogen corresponded to broad patterns of nitrogen inputs from agricultural and urban areas. Coastal waters near such areas of high nitrogen input are at greatest risk of eutrophication.

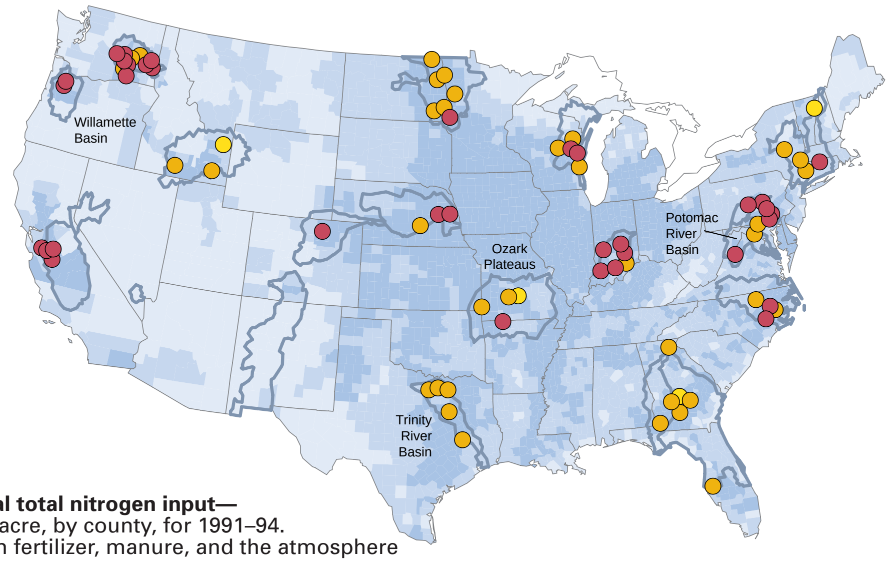


During high spring streamflows following fertilizer application in the northern Willamette Basin, nitrate concentrations increased in proportion to the percentage of drainage area in agriculture. Nutrient concentrations also were found to increase with the percentage of drainage area in agriculture for watersheds in the Ozark Plateaus, Potomac River Basin, and Trinity River Basin.

A national ranking of TOTAL NITROGEN concentrations in streams

Average annual concentration of total nitrogen—
in milligrams per liter

- Highest (greater than 2.9)
- Medium (0.6 to 2.9)
- Lowest (less than 0.6)

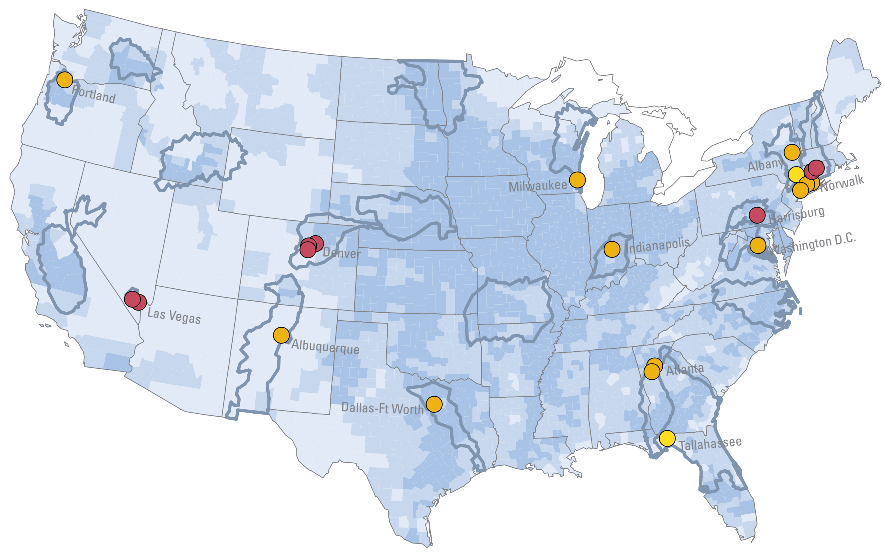


Average annual total nitrogen input—
in pounds per acre, by county, for 1991–94.
Inputs are from fertilizer, manure, and the atmosphere

- Highest (greater than 25)
- Medium (6 to 25)
- Lowest (less than 6)

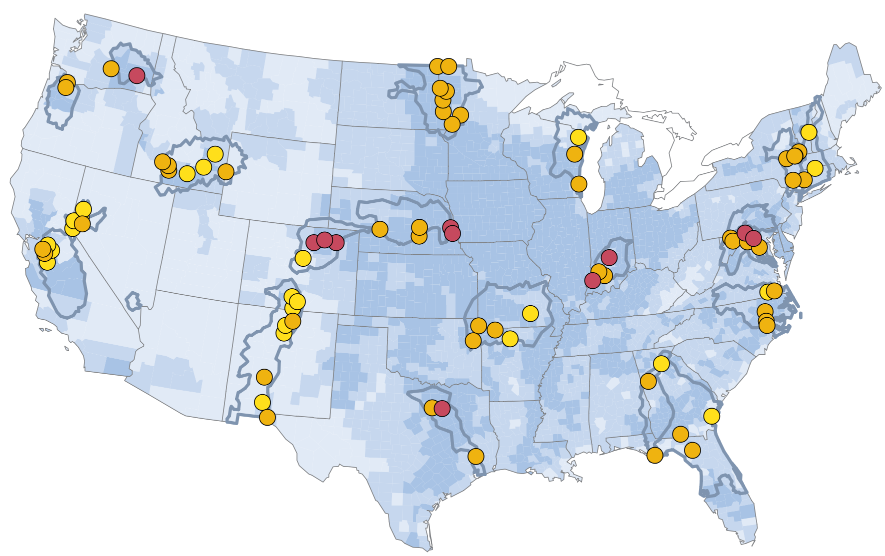
Agricultural streams

Total nitrogen concentrations in agricultural streams were among the highest measured and generally correlated with nonpoint nitrogen inputs across the Nation.



Urban streams

The highest total nitrogen concentrations in urban streams typically were in densely populated areas in relatively arid Western basins and in the Northeast.



Rivers and streams with mixed land use

Total nitrogen concentrations generally correlated with nonpoint nitrogen inputs, but levels in large rivers downstream from major metropolitan areas were among the highest measured.

See p. 31 for more information about these maps

PHOSPHORUS IN STREAMS

In most streams draining agricultural, urban, or mixed land use, concentrations of total phosphorus were greater than background concentrations and the USEPA desired goal for preventing nuisance plant growth in streams. About one-half of urban streams had average annual concentrations of total phosphorus that ranked among the highest measured in the first 20 Study Units. The highest average annual concentrations of total phosphorus were in streams near metropolitan areas in the semiarid western and southwestern regions of the Nation. Examples include the Santa Fe River downstream from Santa Fe, New Mexico; Las Vegas Wash downstream from Las Vegas, Nevada; and the South Platte River downstream from Denver, Colorado. In these areas, discharges from wastewater treatment plants can be a significant proportion of the streamflow.

The broad geographical pattern observed for concentrations of total nitrogen in streams also holds true for concentrations of total phosphorus. This comparability is not surprising because proportions of nitrogen and phosphorus fertilizer used across the Nation are similar. Elevated phosphorus concentrations in agricultural streams can also come from livestock waste, such as in Prairie Creek in the Central Nebraska Basins, or from poultry wastes, such as in streams of the Apalachicola-Chattahoochee-Flint River Basin and the Ozark Plateaus. In addition, agricultural sites can be affected by effluent from upstream wastewater treatment plants, such as in Turlock Irrigation District Lateral 5 in the San Joaquin-Tulare Basins. Some high concentrations of phosphorus can occur naturally. For example, concentrations of phosphorus in the Pembina River of the Red River of the North Basin were high because most agricultural land in this area includes phosphorus-rich soils in relatively steep, easily eroded terrain; high concentrations of phosphorus in some streams in the Albemarle-Pamlico Drainage were derived from ground water in contact with phosphate minerals.

Concentrations of total nitrogen and total phosphorus typically were low in large rivers that drain areas of mixed land use. Examples include the Altamaha River, Georgia; Connecticut River, Connecticut; Menominee River, Wisconsin; and Upper Snake River, Idaho. In these large watersheds, streams draining forested and other relatively undeveloped land dilute nutrient-rich runoff from agricultural and urban areas. A few large rivers (such as the South Fork of the Palouse River, Washington, and the Trinity River, Texas) had extremely high average annual concentrations of total nitrogen and (or) total phosphorus that can be attributed primarily to the effect of upstream discharges of wastewater effluent. Large watersheds dominated by agricultural land, such as in the Great Plains and Upper Midwest, also exhibited concentrations of total phosphorus that ranked among the highest measured.

Kevin F. Dennehy

Effluent can make up a substantial part of the streamflow in some areas. For example, wastewater treatment plants annually contribute about 69 percent (and at times 100 percent) of the flow in the South Platte River downstream from Denver, Colorado. About 1,200 tons of phosphorus enter the South Platte River Basin every year from wastewater treatment plants.

Phosphorus transport in watersheds is complex. Phosphorus commonly attaches to soil particles and either remains close to application areas or moves to streams primarily by soil erosion. As phosphorus levels increase in some soils, a larger amount is available for transport in the dissolved form. This amount varies according to the phosphorus adsorption capacity of the soil. Areas with high levels of soil phosphorus relative to their soil adsorption capacity export relatively large amounts of phosphorus to streams.

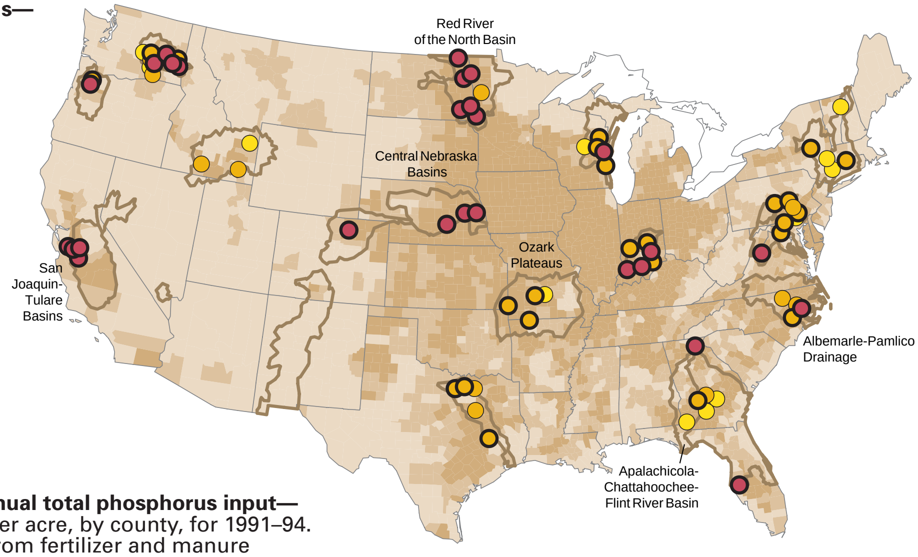
A national ranking of TOTAL PHOSPHORUS concentrations in streams

Average annual concentration of total phosphorus—
in milligrams per liter

- Highest (greater than 0.25)
- Medium (0.045 to 0.25)
- Lowest (less than 0.045)

Background concentration

- Bold outline indicates median values greater than background concentration (0.1 milligram per liter)

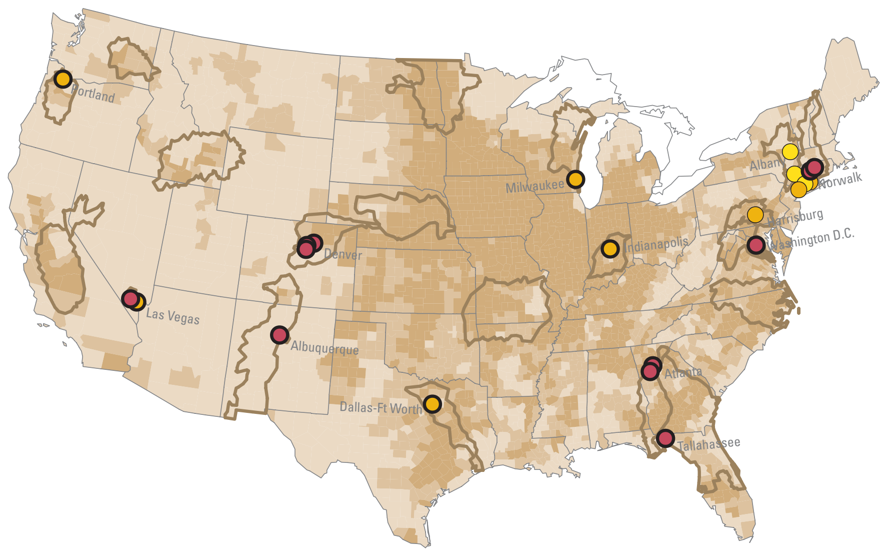


Agricultural streams

Total phosphorus concentrations in agricultural streams were among the highest measured and generally correlated with nonpoint phosphorus inputs across the Nation.

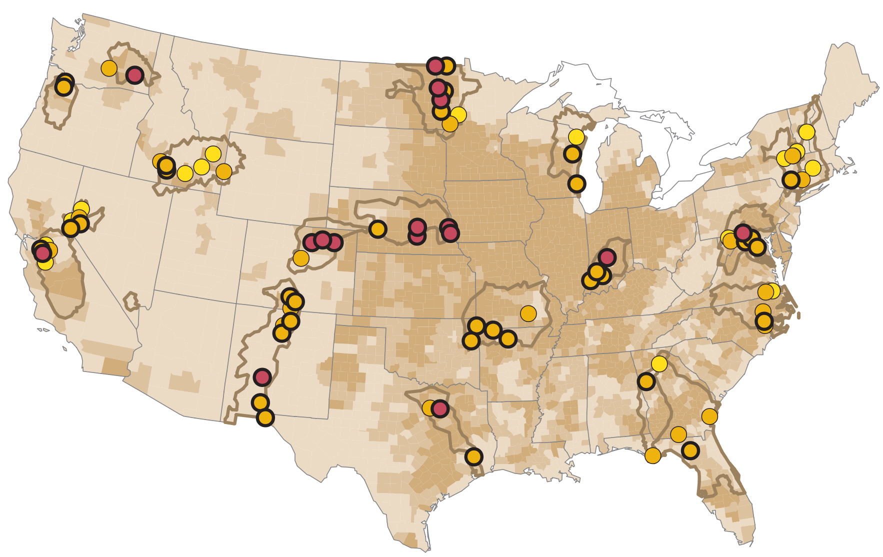
Average annual total phosphorus input—
in pounds per acre, by county, for 1991–94.
Inputs are from fertilizer and manure

- Highest (greater than 5)
- Medium (2 to 5)
- Lowest (less than 2)



Urban streams

The highest total phosphorus levels in urban streams typically were in densely populated areas in relatively arid Western basins and in the East.



Rivers and streams with mixed land use

Total phosphorus concentrations generally correlated with nonpoint phosphorus inputs; however, in contrast to total nitrogen, levels in large rivers were highest in the Midwest, Great Plains, and West, where high concentrations of suspended sediment from erosion are common.

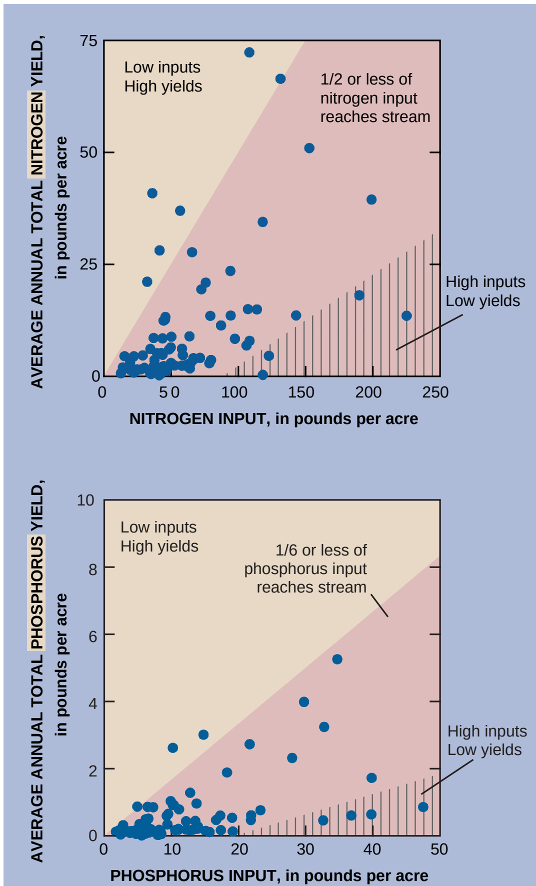
See p. 31 for more information about these maps

Differences in occurrence and behavior of nutrients complicate prediction of effects and management options

NUTRIENT INPUTS AND ENVIRONMENTAL FACTORS CONTROL NUTRIENT LOSSES FROM WATERSHEDS TO STREAMS

Enrichment of streams with nutrients is not simply explained by differences in land use. Land-management practices, nitrogen inputs to the land surface, local and regional environmental characteristics, and seasonal effects also control the degree of enrichment. Such an integration of factors explains why nutrient concentrations can be so different in different regions of the Nation, despite seemingly similar land-use settings.

Nutrient inputs to the land are key to explaining variations in the amount of nutrients lost from watersheds to streams (nutrient yields). The amounts of nutrients reaching streams generally increase as the total nonpoint nutrient inputs increase. For streams, nitrogen yields were less than or equal to about one-half of the total nonpoint inputs of nitrogen from the atmosphere, commercial fertilizer, and manure. This is consistent with the tendency of nitrate to dissolve in water and be transported with surface and subsurface runoff. Phosphorus yields, on the other hand, were less than or equal to about one-sixth of the total phosphorus inputs from commercial fertilizer and manure. Again, this is consistent with the general tendency of phosphorus to readily attach to soil particles rather than to dissolve in water that runs off to streams or seeps to ground water. In watersheds where crops and other plants cannot use all nutrients applied during a growing season, excess nutrients may be available for runoff to streams.



Average annual total nitrogen and total phosphorus yields to agricultural streams generally increase as nutrient inputs increase; however, a greater proportion of nitrogen than phosphorus input generally was lost to streams. The large amount of scatter in the data can be explained by local differences in agricultural practices, soils, geology, and hydrology across the Nation.

Local watershed characteristics and environmental settings also play key roles in determining nutrient yields. Watersheds with high nitrogen yields compared to total nitrogen inputs include Bachman Run, East Mahantango Creek, Kishacoquillas Creek, and Muddy Creek in the Lower Susquehanna River Basin; Broad Brook in the Connecticut, Housatonic, and Thames River Basins; and Zollner Creek in the Willamette Basin. These agricultural streams generally are in areas of high precipitation, which enhances runoff of surface water and flushing of shallow ground water, along with nitrogen, to streams. These watersheds also have a long history of farming, and they are located where soils and underlying geologic formations allow rapid movement of nitrogen-rich water through shallow aquifers and into streams.

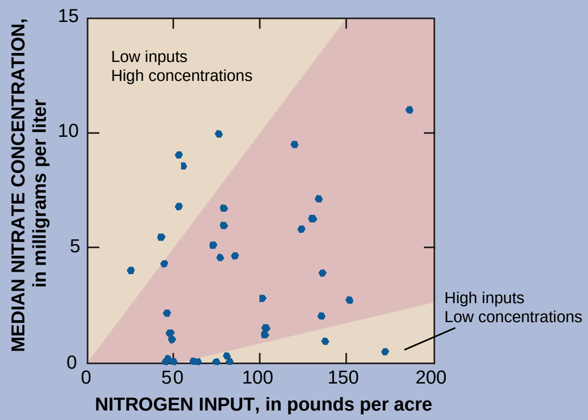
Characteristics of soil drainage can accentuate or mitigate nutrient yields to streams. For example, the Lost River in the White River Basin exhibited high nitrate and phosphorus yields, particularly during high-flow conditions. Despite relatively low nutrient inputs, high nutrient yields probably result from sloping, clayey soils and shallow depth to permeable karst bedrock, which allow rapid transport of nutrients to the Lost River. Watersheds with high nitrogen inputs and low nitrogen yields, such as Prairie and Shell Creeks in the Central Nebraska Basins, have relatively flat-lying, sandy or silty soils where water infiltrates readily and nitrate migrates to shallow ground water instead of being transported to streams.

Environmental factors controlling phosphorus yields to streams can be different from those controlling nitrogen yields. Watersheds with low phosphorus inputs and high phosphorus yields include Bullfrog Creek in the Georgia-Florida Coastal Plain—an unusual case reflecting contributions from naturally occurring phosphate minerals—and Broad Brook in the Connecticut, Housatonic, and Thames River Basins, which receives supplemental fertilization from phosphorus-rich manure. Basins with high phosphorus inputs and low yields include streams in the Lower Susquehanna River Basin, San Joaquin-Tulare Basins, and Albemarle-Pamlico Drainage. These streams gain significant flow from ground-water discharge, a source typically low in phosphorus because phosphates tend to be retained by the soil. Some of these same streams receive ground water that is high in nitrate because nitrogen inputs to the basins are high and nitrate can remain in solution. This is particularly true where denitrification, a microbial process that can transform nitrate to nitrogen gas, is not a controlling factor.

NITROGEN INPUTS AND ENVIRONMENTAL FACTORS CONTROL NITRATE CONCENTRATIONS IN SHALLOW GROUND WATER

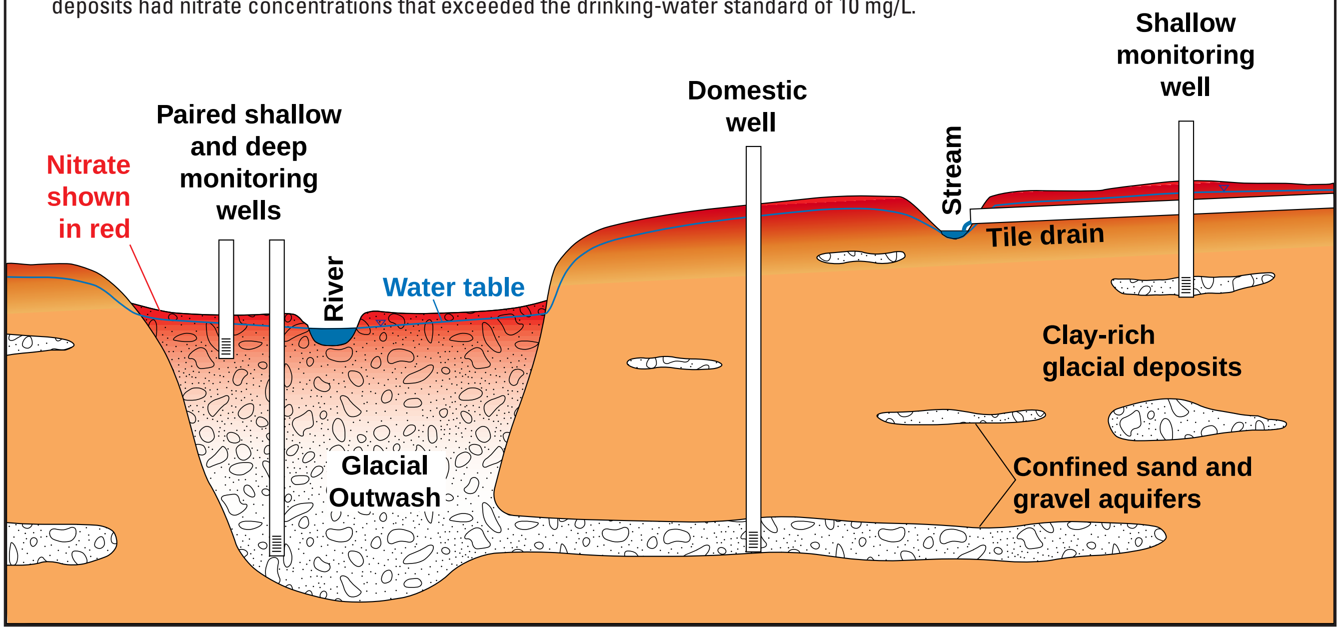
Local differences in soils, geology, and hydrology affect nitrate migration from nonpoint sources to ground water in a more pronounced way than for nutrient yields to streams. Inputs of nitrogen were estimated from atmospheric, commercial fertilizer, and manure sources for areas within a one-third-mile radius of each monitoring well. Study areas with low inputs of nitrogen and high median nitrate concentrations (greater than about 4 mg/L) generally are underlain by karst or fractured rock or by unconsolidated sand and gravel that allow nitrate to move readily to shallow ground water. Such areas are found in the San Joaquin-Tulare Basins, Central Columbia Plateau, Red River of the North Basin, Western Lake Michigan Drainages, Lower Susquehanna River Basin, Potomac River Basin, and Connecticut, Housatonic, and Thames River Basins.

Areas with high nitrogen inputs but low median nitrate concentrations (less than about 2 mg/L) generally are underlain by relatively impermeable rock, silt, or clay, which impede downward movement of water. Examples of these areas are found in the Rio Grande Valley, White River Basin, and Western Lake Michigan Drainages. The Jerome-Gooding agricultural site in the Upper Snake River Basin also fell in the high-input and low-concentration group, but this was more likely related to the deep water table (median of 153 feet) in this area.



A plot of nitrogen inputs to agricultural land versus median nitrate concentrations in underlying shallow ground water shows considerable scatter. Porous soils and bedrock, which allow rapid downward movement of water and nitrate, underlie areas with low nitrogen inputs and high nitrate concentrations in shallow ground water. Areas with high inputs and low concentrations generally are underlain by less permeable geologic materials.

Nitrate concentrations in ground water generally were less than 0.1 mg/L in many parts of the White River Basin even though it receives some of the highest nitrogen fertilization rates in the Nation. The White River Basin is in the Upper Midwest, which contains some of the highest percentages of cropland (58 percent) and corn cropland (30 percent) in the United States. Nitrogen fertilization rates for corn often exceed 200 pounds per acre. Despite high nitrogen input rates, nitrate concentrations (shown in red, below) typically are low in ground water. This occurs because (1) poorly drained and impermeable glacial deposits, such as clay and silt, restrict the downward movement of water and nitrate to the water table, (2) nitrate is intercepted and transported to streams by tiles and ditches in many areas, and (3) nitrate is converted by denitrification to other forms of nitrogen where dissolved-oxygen concentrations in ground water are low. However, nitrate concentrations can be locally elevated in areas formerly traversed by glacial streams. The streams deposited coarse-textured and well-drained sand and gravel that allow rapid infiltration of water and enable nitrate to move below the root zone before it can be taken up by plants. Seventeen percent of shallow wells in these deposits had nitrate concentrations that exceeded the drinking-water standard of 10 mg/L.



Nutrient concentrations vary seasonally

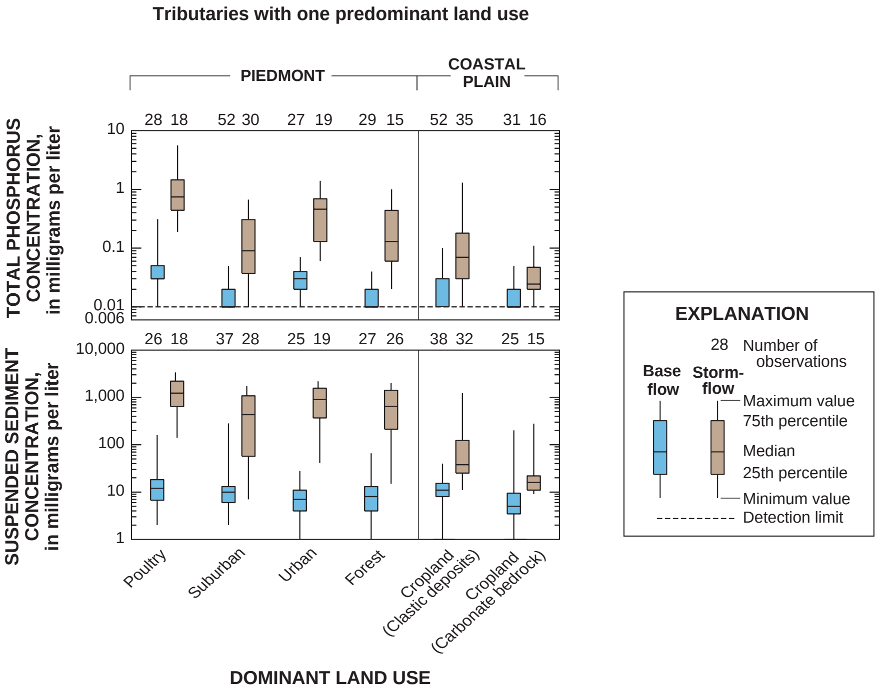
Nutrient concentrations vary throughout the year, largely in response to changes in precipitation and streamflow and to differences in time since fertilizer or manure application. Nutrient concentrations in streams typically are elevated during high spring and summer streamflows, or peak irrigation periods, following fertilizer application. In two agricultural streams in the Western Lake Michigan Drainages, for example, more phosphorus was transported during storms in June 1993 than during the 24 months that followed.

High nutrient concentrations also can be found in streams during seasonal low-flow conditions. Nitrate concentrations in agricultural streams can be high during winter low flow because of contributions from ground-water discharge and (or) because algal uptake is low. Nitrogen and phosphorus concentrations in streams downstream from metropolitan areas may be highest during various seasonal low flows, when contributions from point sources are greater relative to streamflow, and dilution is less.

Nitrate levels in shallow ground water can change throughout the year, but typically the seasonal changes are noticeable only in the upper 5-10 feet of the water table in surficial aquifers. For example, nitrate concentrations in shallow ground water from less than 10 feet below the water table in parts of the Red River of the North Basin ranged from about 8 to 25 mg/L from March 1994 through September 1995. This variation was related in part to the timing of important recharge periods, which generally occurred when spring snowmelt and major summer rainstorms coincided with irrigation periods, and in part to variations in the timing and application of fertilizers applied to crops.

W.H. Mullins © 1980

Nitrate concentrations in shallow ground water beneath agricultural land can change seasonally in response to irrigation patterns.



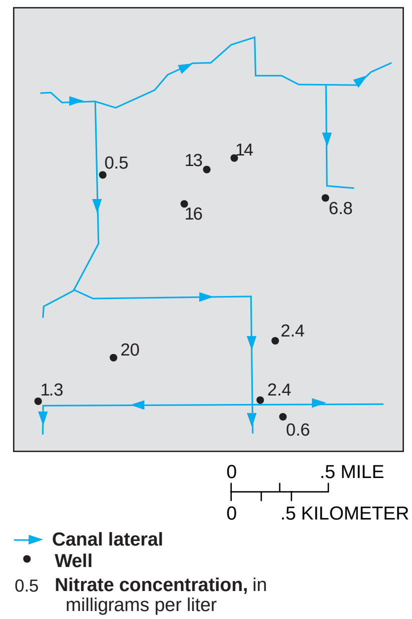
Total phosphorus concentrations in streams of the Apalachicola-Chattahoochee-Flint River Basin were higher during stormflow than during low flow and correlated with suspended sediment concentrations from March 1993 through September 1995

Stream-aquifer interactions control nitrate concentrations near some stream reaches

Irrigation and agricultural drainage can play a major role in the timing and magnitude of nutrient concentrations, particularly in the western part of the Nation, where large fluctuations in streamflow occur because of diversions for irrigation. Return flows from agricultural land during the irrigation season can account for most of the flow in many western streams and rivers, and concentrations of potential contaminants often are highest during peak irrigation periods. In addition, low nutrient concentrations in irrigation canals can dilute concentrations in ground water in areas where direct connections occur between the canals and adjacent aquifers.

Stream-aquifer interactions can affect nutrient concentrations differently during different times of the year in the same river reach. For example, nitrate concentrations in shallow ground water adjacent to the lower Suwannee River in the Georgia-Florida Coastal Plain vary seasonally because of a cycle of water exchange between the river and the adjoining aquifer. During summer low flow, ground water containing high nitrate concentrations enters the river, increasing river nitrate concentrations. During spring high flow, river water low in nitrate enters the aquifer, resulting in a decrease in ground-water nitrate concentrations adjacent to the river.

Stream-aquifer interactions also can affect nutrient concentrations differently in different parts of the same river basin. For example, nitrate concentrations in about one-half of the wells sampled near the South Platte River in Colorado exceeded the USEPA drinking-water standard. Ground water contributes a substantial amount of flow to the river in this area, but concentrations of nitrate in the river were substantially lower than in ground water because microbial denitrification removed nitrate as ground water passed through the streambed. Farther downstream in Nebraska, ground water in the alluvial aquifer adjacent to the Platte River is used for public supply by Nebraska's largest cities, including Omaha, Lincoln, Grand Island, and Kearney. Pumping water from wells in this aquifer induces flow of Platte River water into the aquifer and has the potential to decrease nitrate concentrations in the ground water.



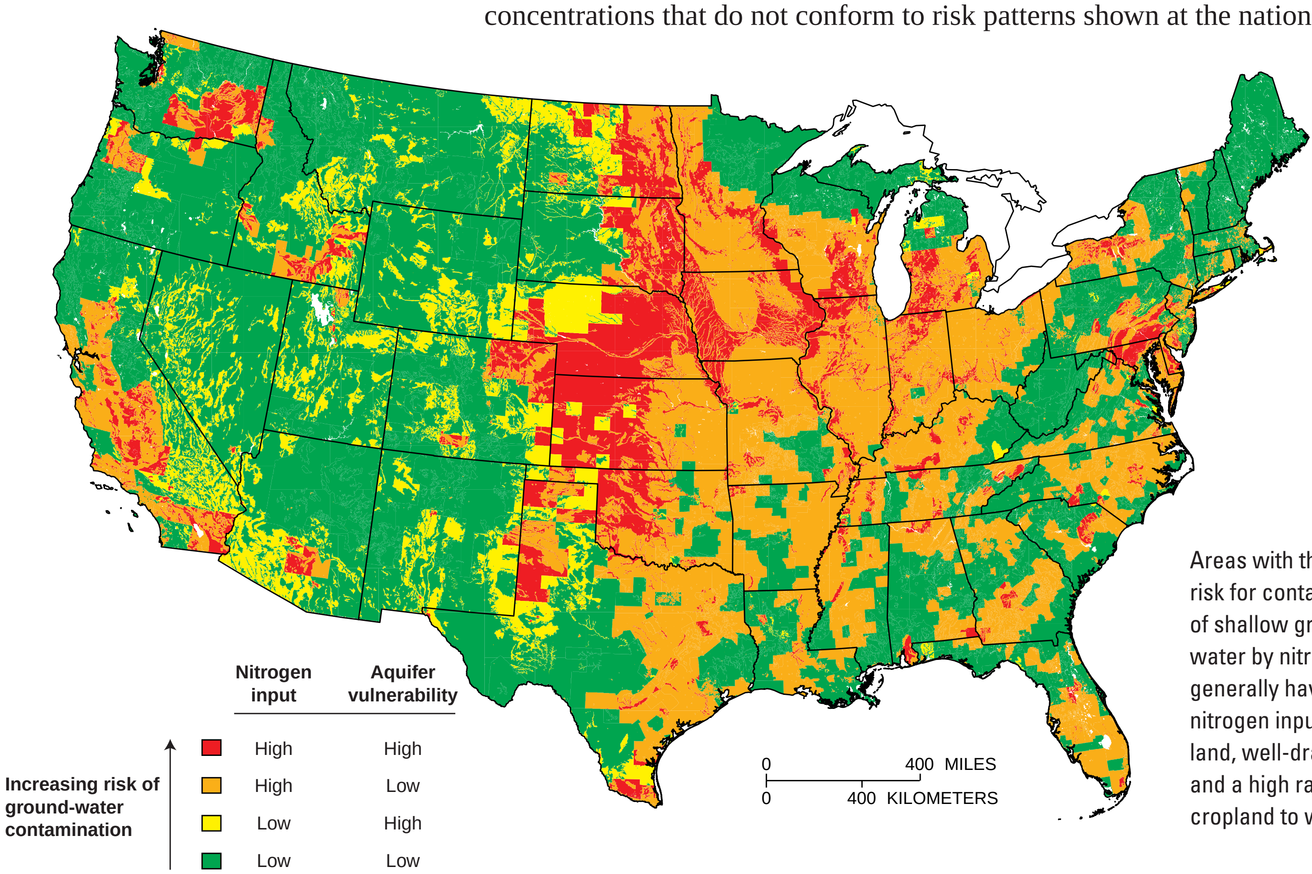
Water from irrigation canals effectively decreases nitrate concentrations in ground water in the Quincy-Pasco area of the Central Columbia Plateau. Columbia River water diverted for irrigation leaks from canals and decreases nitrate concentrations by dilution in shallow ground water near the canals.

Modeling integrates information to estimate risks of nitrate contamination to shallow ground water

Models can integrate information on chemical use, land use, and environmental factors to help explain water-quality conditions over broad geographic regions. One USGS model, based on nationwide data, was developed to estimate the risk of nitrate contamination to shallow ground water across the United States.(30) The model integrates nitrogen inputs and aquifer vulnerability by use of Geographic Information System (GIS) technology. Nitrogen inputs include commercial fertilizer and manure application rates, atmospheric contributions, and population densities (the latter representing residential and urban nitrogen sources, such as septic systems, fertilizers, and domestic animal waste). Aquifer vulnerability is represented by soil-drainage characteristics—the ease with which water and chemicals can seep to ground water—and the extent to which woodlands are interspersed with cropland.

Nitrate concentrations measured in the first 20 Study Units generally conform to the national risk map. Nitrate concentrations are expected to be lowest in the areas shown in green, where nitrogen inputs and aquifer vulnerability are lowest, and highest in the areas mapped in red, which represent regions where nitrogen inputs and aquifer vulnerability are highest. **Anticipating where and what types of nitrate conditions exist can help focus regional or national water-management goals and monitoring strategies on the most vulnerable areas.**

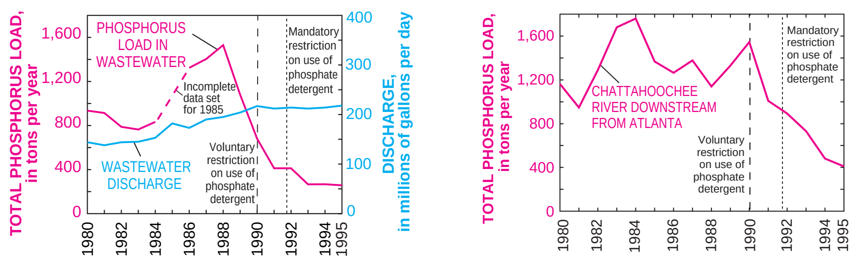
Use of the risk map to identify and prioritize contamination at a more detailed level than presented here is not advised because local variations in land use, irrigation practices, aquifer type, and rainfall can result in nitrate concentrations that do not conform to risk patterns shown at the national scale.



Areas with the highest risk for contamination of shallow ground water by nitrate generally have high nitrogen inputs to the land, well-drained soils, and a high ratio of cropland to woodland.

Nutrient conditions have changed over time in streams

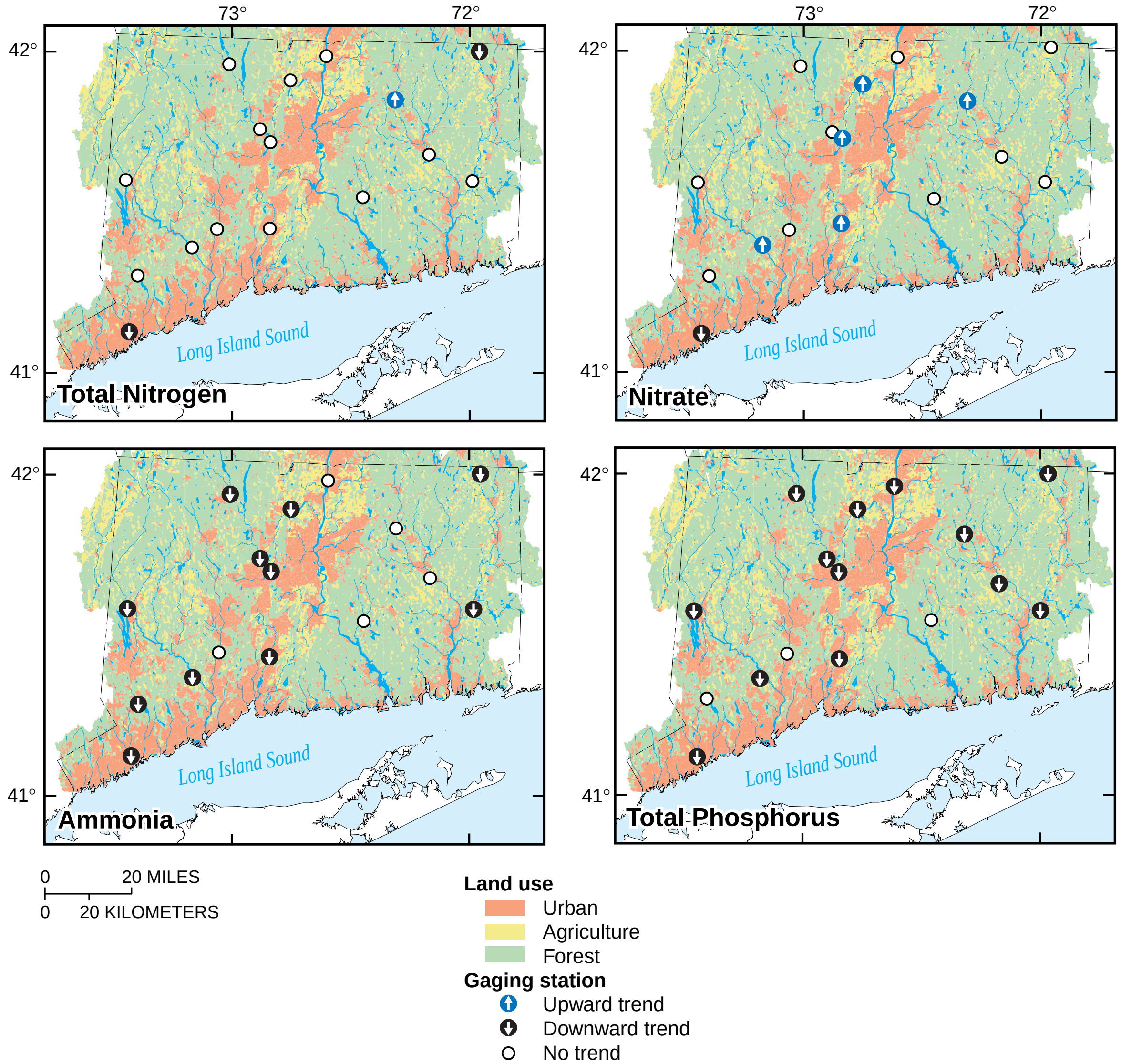
Decades of monitoring may be necessary to adequately assess the effects of land- and water-management decisions on water quality. For example, decreases in phosphorus concentrations resulting from improved wastewater treatment technology and phosphate detergent bans have been documented in the Apalachicola-Chattahoochee-Flint River Basin; Albemarle-Pamlico Drainage; Connecticut, Housatonic, and Thames River Basins; Lower Susquehanna River Basin; Potomac River Basin, and Western Lake Michigan Drainages.



Improvements in wastewater treatment and bans on phosphate detergents have resulted in decreased phosphorus concentrations in the Chattahoochee River downstream from Metropolitan Atlanta. Wastewater discharge to the Chattahoochee River from the six largest Metropolitan Atlanta wastewater treatment facilities increased by about 50 percent from 1980 to 1995; however, the total phosphorus load from these facilities decreased by about 83 percent relative to the highest load recorded in 1988. Improvements in wastewater treatment account for about two-thirds of the decrease in phosphorus load, and restrictions on phosphate detergents account for about one-third of the decrease. By 1995, decreased phosphorus loads from point sources had resulted in total phosphorus loads in the Chattahoochee River downstream from Metropolitan Atlanta that were 77 percent less than the highest load measured in the Chattahoochee River in 1984.

Ammonia has decreased, but nitrate has increased, in the Trinity River downstream from Dallas, Texas. As a result of upgrades to wastewater treatment plants in the Dallas area, concentrations of ammonia plus organic nitrogen decreased about 95 percent from 1974 to 1991 at five sites on the Trinity River. Nitrate concentrations increased by a similar magnitude during the same period because the ammonia was converted to nitrate. The decrease in ammonia has led to an increase in dissolved oxygen, which reduces the threat of fish kills.

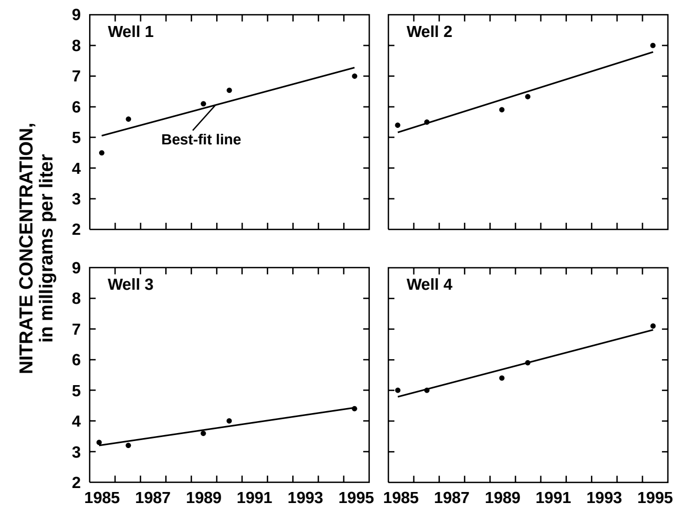
Despite decreases in ammonia and phosphorus in the Connecticut, Housatonic, and Thames River Basins, nutrients are still considered an environmental concern in Long Island Sound. Significant downward trends in total phosphorus concentrations were documented in 13 of 16 streams and rivers from 1980 to 1992 in the Connecticut, Housatonic, and Thames River Basins. The decreased phosphorus concentrations are likely due to improvements in wastewater treatment and to the elimination or reduction of phosphates in detergents. Ammonia decreased and nitrate increased during the same period, primarily as a result of the improved wastewater treatment processes, which convert ammonia to nitrate. Although improved treatment technology has enhanced surface-water quality in many parts of the Study Unit, the total amount of nutrients (particularly nitrogen) discharged to Long Island Sound is still considered an environmental concern. Excess nutrients continue to cause algal blooms, which decay and result in low dissolved-oxygen concentrations and poor habitat for fish and other marine animals in the Sound.



Removal of ammonia from point sources has enhanced stream quality in several Study Units, including the Connecticut, Housatonic, and Thames River Basins; Lower Susquehanna River Basin; Potomac River Basin; San Joaquin-Tulare Basins; and Trinity River Basin. Ammonia removal generally involves conversion to nitrate, and decreased ammonia concentrations typically have been accompanied by increased nitrate concentrations. Consequently, total nitrogen concentrations in these streams have remained about the same. Although toxicity to aquatic life has decreased as a result of ammonia removal, potential for eutrophication of surface waters probably has not changed.

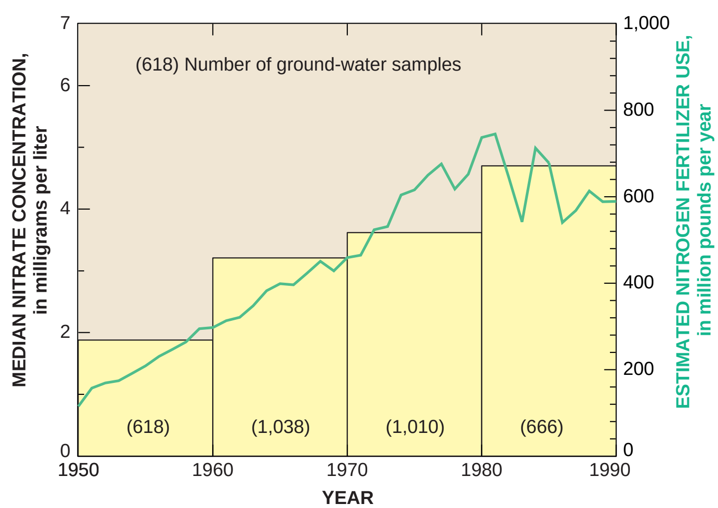
Nutrient conditions have changed over time in ground water

Little information exists about trends of nitrate in ground water, particularly at a national scale, because few monitoring programs have been designed to look at the quality of ground water over time. Some information on nitrate trends is available, however, for the Upper Snake River Basin and San Joaquin-Tulare Basins. Studies in the San Joaquin Valley indicate that from 1950 to 1980, the largest source of nitrate (nitrogen fertilizer) increased from 114 to 745 million pounds per year. Concentrations of nitrate in ground water also increased, from less than 2 mg/L in the 1950s to about 5 mg/L in the 1980s.



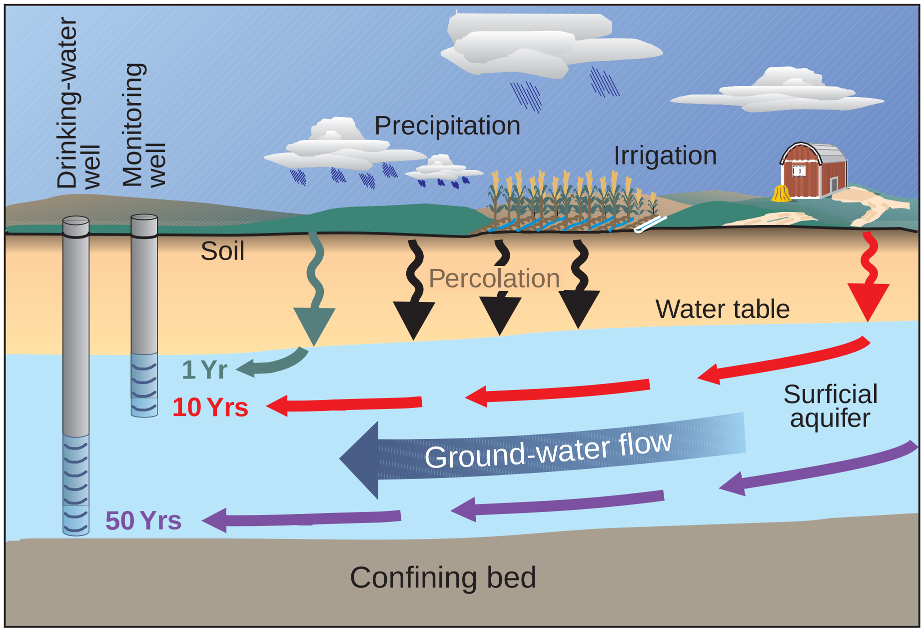
Concentrations of nitrate in shallow ground water have increased in agricultural areas of the Upper Snake River Basin. Water from four wells (average depth, 40 feet) in the alluvial aquifer in the Minidoka Irrigation District north of Burley, Idaho, showed an increase in nitrate between 1985 and 1995.

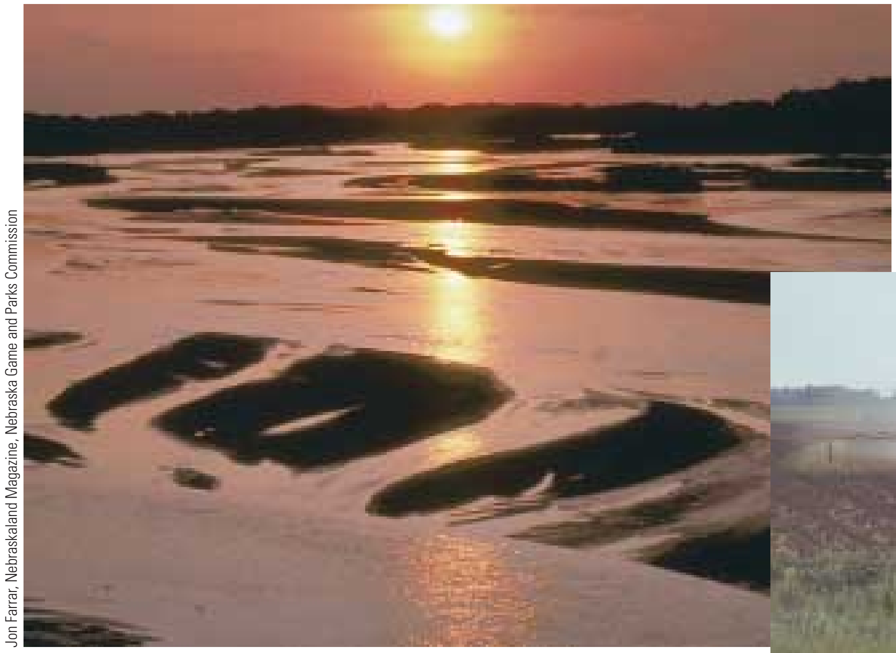
Neil M. Dubrovsky



Fertilizer use and nitrate concentrations in ground water in the eastern San Joaquin Valley (left) generally have increased over the last four decades. Although confined animal feeding operations and manure production also have increased during this period, nitrogen fertilizer is still considered to be the largest single source of nitrate to ground water.

The effects of past and present land-use practices may take decades to become apparent in ground water. When weighing management decisions for protection of ground-water quality, it is important to consider the time lag between application of nitrogen to the land and arrival of nitrate at a well. This time lag generally decreases with increasing aquifer permeability and with decreasing depth to water. In response to reductions in nitrogen applications to the land, the quality of shallow ground water will improve before the quality of deep ground water, which could take decades.





Nitrate concentrations have decreased in shallow ground water in parts of the Central Nebraska Basins. In the mid-1980s, the Central Platte Natural Resources District (CPNRD) established fertilizer management areas in part of the central Platte Valley, where nitrate concentrations were as high as 40 mg/L. Stringent guidelines were imposed on the timing and application rates of fertilizer in an area where the median nitrate concentration had increased from about 8 mg/L in 1974 to about 18 mg/L in 1986. In 1994, after implementation of the fertilizer management strategy, the median nitrate concentration decreased to less than 2 mg/L. It is important to note, however, that local variations in soil characteristics, amounts of recharge, and other factors affect responses to management strategies: nitrate concentrations in nearly 25 percent of the wells sampled by the CPNRD in the area with the most stringent guidelines continued to exceed 20 mg/L in 1994.