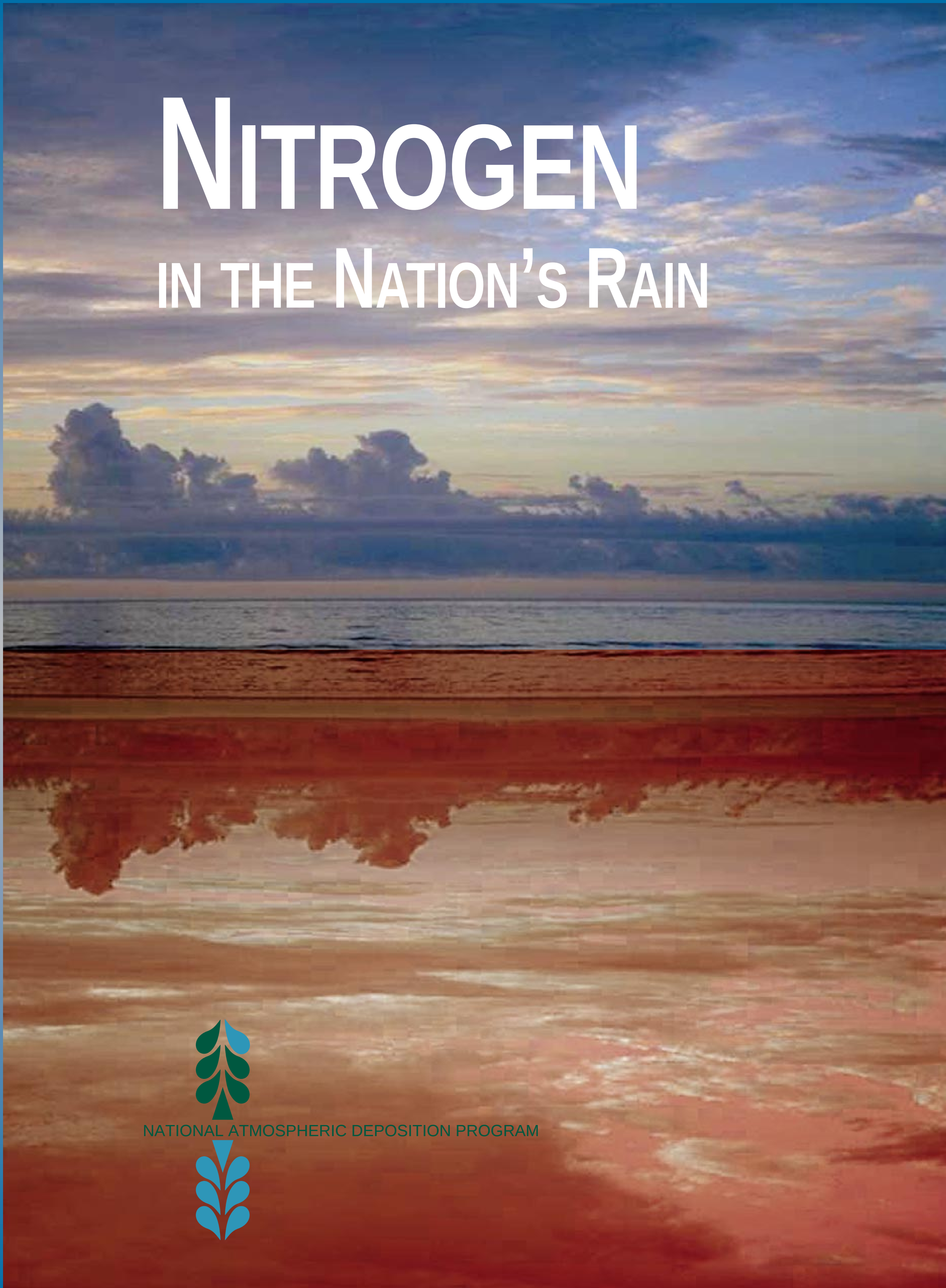
NITROGEN IN THE NATION'S RAIN



NATIONAL ATMOSPHERIC DEPOSITION PROGRAM

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Nitrogen in the Nation's Rain

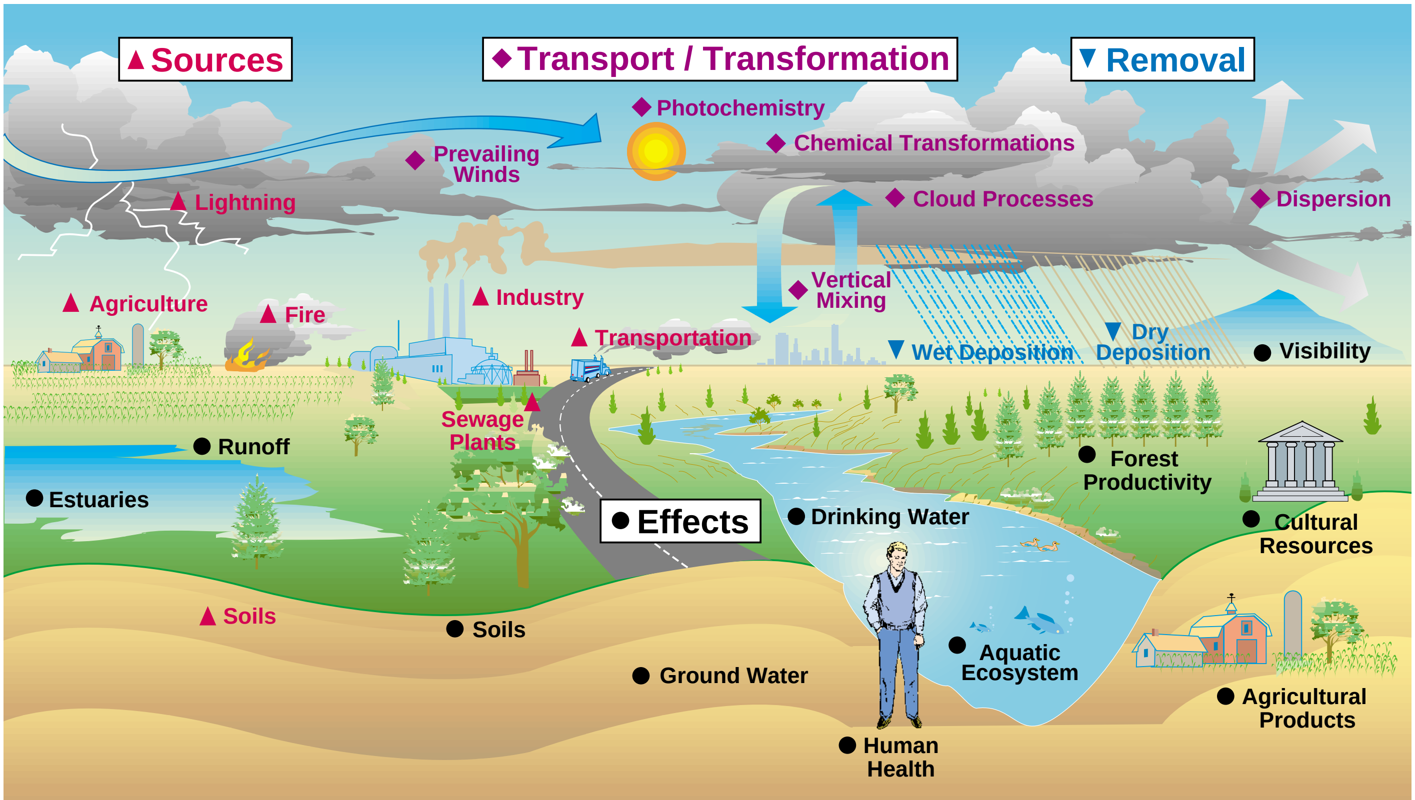
Nitrogen is essential for all living things. Nearly 98% of the world's nitrogen is found in the solid earth within the chemical structure of rock, soil, and sediment. The remainder moves in a dynamic cycle involving the atmosphere, oceans, lakes, streams, plants, and animals. Small amounts of the nitrogen in soil and sediment also enter this complex cycle.

Molecular nitrogen (N_2) is a colorless odorless gas that comprises 78% of our atmosphere. Nearly 8 metric tons of nitrogen sit atop every square meter of the earth's surface. Molecular nitrogen is stable and converting it to other chemical compounds requires considerable energy. A lightning bolt provides sufficient energy to do the job, causing some nitrogen and oxygen in the air to form nitrogen oxides. Photosynthetic energy in plants and chemical energy in soil microorganisms also can convert nitrogen to other chemical forms. All of these natural processes occur in the cycling of nitrogen in our environment.

In addition to molecular nitrogen, trace amounts of nitrogen oxides, nitric acid vapor, gaseous ammonia, particulate nitrate and ammonium compounds, and organic nitrogen circulate through the atmosphere. In the United States, nitrogen contributions from human activities rival or exceed contributions from natural sources for many of these trace compounds.

Atmospheric nitrogen compounds cycle to the land and water through atmospheric deposition. Wet deposition, predominantly rain and snow, carries nitrate and ammonium. Dry deposition involves complex interactions between airborne nitrogen compounds and plant, water, soil, rock, or building surfaces.

Key issues for scientists, policymakers, and the public are the extent to which human activities are affecting the form and amount of nitrogen in the air, the deposition of nitrogen compounds from the air, and nitrogen cycling in the environment.



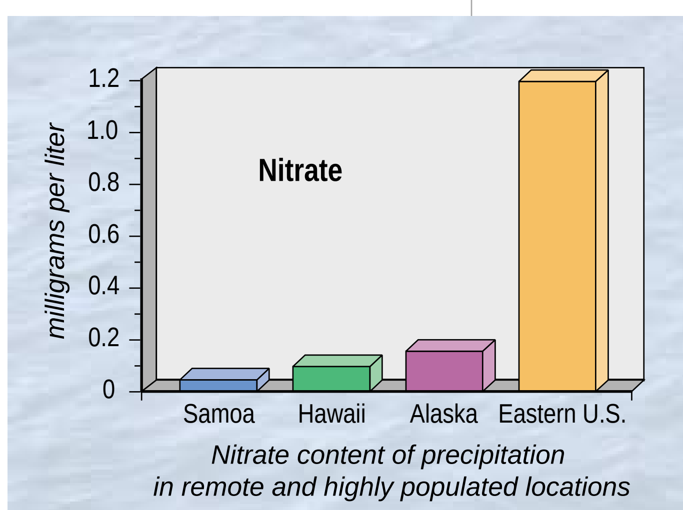
Atmospheric nitrogen pathways.

Source: Adapted from National Science and Technology Council Committee on Environment and Natural Resources, Air Quality Research Subcommittee, 1999.

Which Human Activities Contribute Nitrogen?

Combustion provides high temperatures in which nitrogen can be oxidized to form nitrogen oxides. It's not surprising, then, that emissions from motor vehicles, electric utilities, and industrial boilers are the largest sources of atmospheric nitrogen oxides in the United States. Human activities now account for more than 90% of U.S. nitrogen oxide emissions. According to the U.S. Environmental Protection Agency, nitrogen oxide emissions fluctuated between 20 and 23 million metric tons since 1972, which is double the 1950 value.

Atmospheric chemical reactions that occur when sunlight is present strongly link nitrogen oxides and other trace gases with formation of ozone. Depending on atmospheric conditions, these reactions can occur within several hundred meters of the original nitrogen oxide source or after the pollutants have been carried several hundred kilometers downwind — perhaps crossing state or national borders. Ultimately, some nitrogen oxides are converted to nitric acid vapor or particulate nitrates. Precipitation efficiently removes both pollutants



Nitrate content of precipitation in remote and highly populated locations

Source: National Atmospheric Deposition Program National Trends Network (after J.N. Galloway, G.E. Likens, and M.E. Hawley, 1984. *Science* **226**:829).

from the air. As a consequence, nitrates in precipitation tend to be highest where the air is most polluted with nitrogen oxides. These areas are likely to have high population densities, numerous motor vehicles, and many power plants or industrial boilers.

Ammonia and ammonium are other forms in which nitrogen occurs. Ammonia is a gas that becomes ammonium when dissolved in water or when present in soils or airborne particles. Unlike nitrogen oxides that form during combustion, soil microorganisms naturally form ammonia and ammonium, compounds of nitrogen and hydrogen. Other processes also form these compounds.

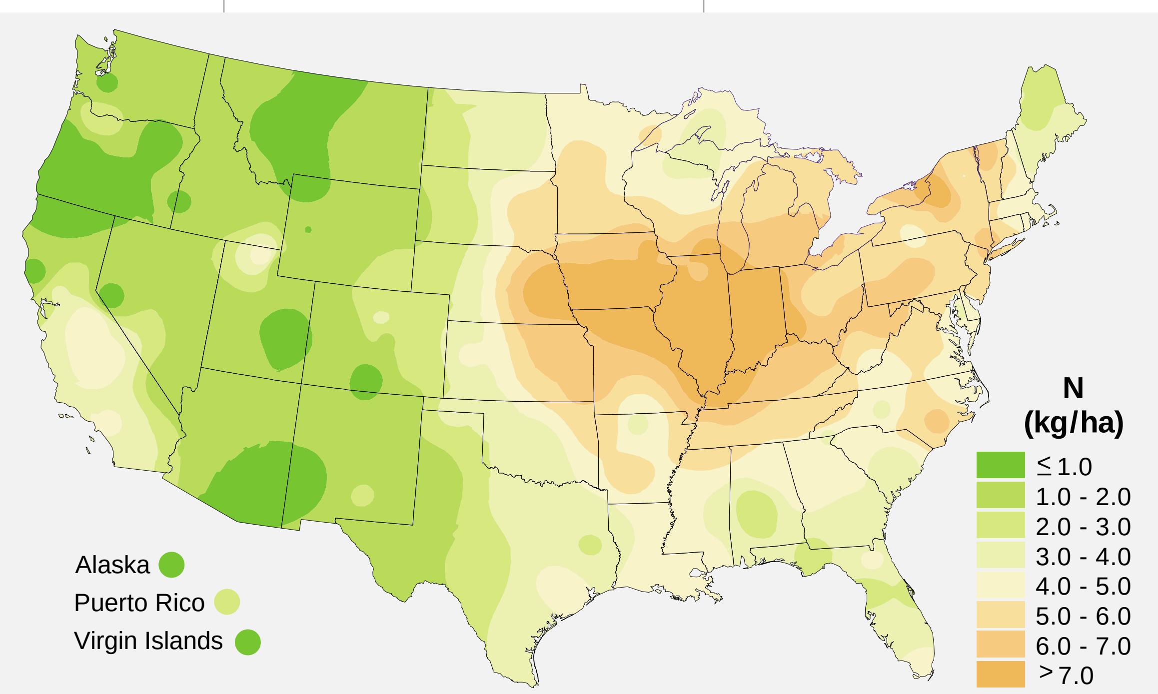
Today, farmers apply millions of tons of nitrogen fertilizers to the soil. The U.S. Environmental Protection Agency estimates that half a million metric tons of ammonia were emitted to the atmosphere from fertilizer applications alone in 1997. More than three times as much was emitted from livestock waste (manure and urine). These two sources account for almost 80% of ammonia emissions in the United States.

Precipitation readily removes ammonia and ammonium from the air. Wet deposition of these compounds and nitrate could be viewed as another source of fertilizer for agricultural crops (see sidebar on agriculture). It can also be an unwanted input of fertilizer to sensitive ecosystems.

The U.S. map below shows the total inorganic nitrogen deposited in precipitation in 1998. Total inorganic nitrogen includes the nitrogen from nitrate ammonium. Wet inorganic nitrogen deposition was highest in the intensely cultivated upper Midwest. Parts of eight states from eastern Nebraska to western Ohio received 7 kilograms per hectare (6.2 pounds per acre) or higher. One-half to three-quarters of the total inorganic nitrogen deposited in this area is from ammonium deposition, which peaks in this same area.

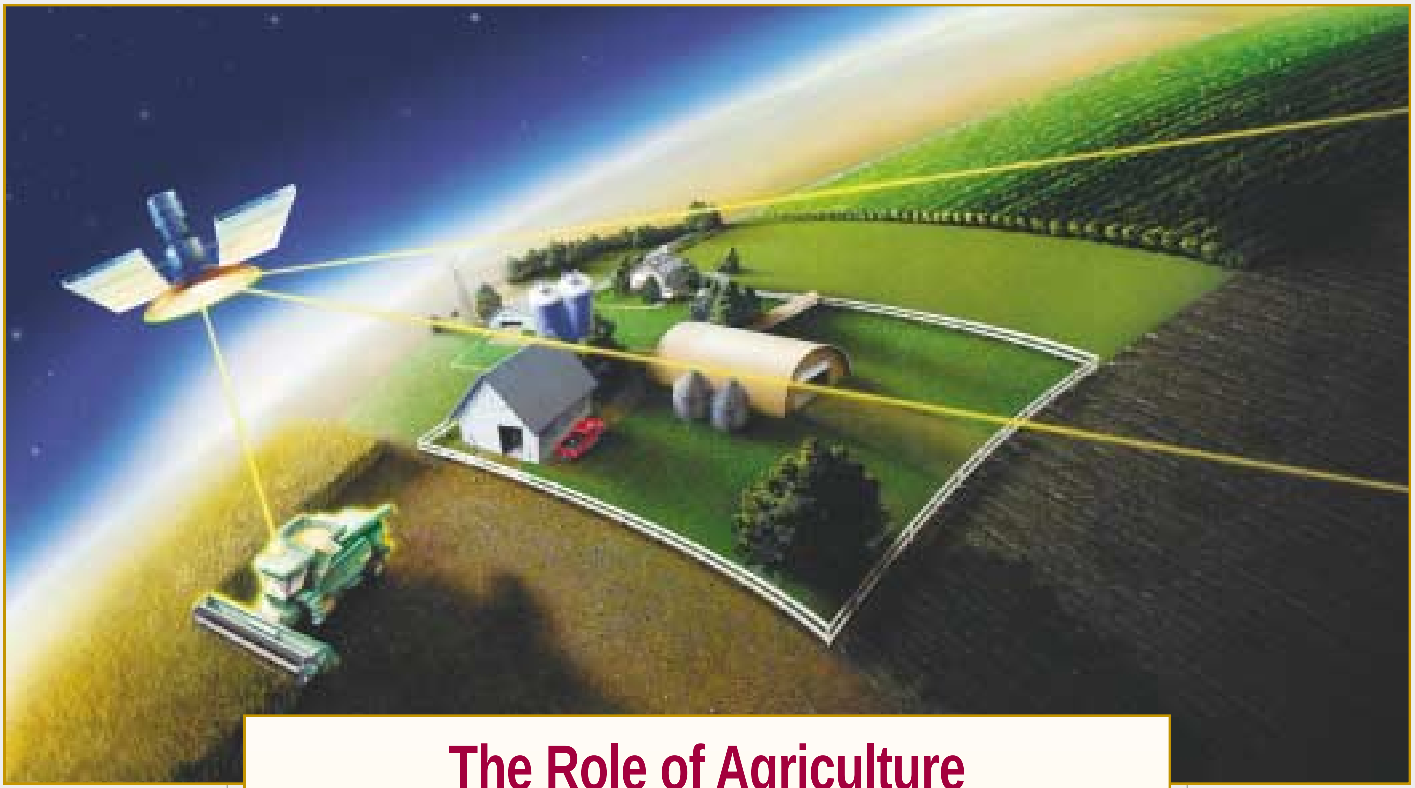
A U.S. Environmental Protection Agency map shows that atmospheric ammonia emissions also peak there. Ammonium-nitrogen dominates the total inorganic nitrogen deposition in the upper Midwest, while nitrate-nitrogen generally dominates in the Northeast.

Areas with the highest nitrogen emissions do not necessarily experience the greatest deposition effects, which can occur far from the original nitrogen source. Scientists have found that some



1998 wet deposition of nitrogen from nitrate and ammonium.

Source: National Atmospheric Deposition Program National Trends Network.



With advances in satellite, computer, and electronics, crop production is moving into a new age.

Graphic courtesy of John Deere - NAAMC.

The Role of Agriculture

Persons engaged in the business of agriculture have a multifaceted interest in nitrogen deposition. Applying nitrogen-based fertilizers has proven very effective in increasing crop yields, but these same fertilizers may be detrimental to the goal of sustainable agriculture and may raise the amount of nitrogen in ground water and surface water downstream of the farmland, contributing to the degradation of aquatic ecosystems. Therefore, one of the major challenges facing environmentally conscious crop producers today is the fertilizer application rates that will optimize crop yield and profit and minimize potential environmental damage. Availability of nitrogen for plant growth and crop yield depends on numerous factors: historical land use, crop type, residual nitrogen from legumes such as soybeans, soil type and condition, amount of nitrogen released by soil organic matter, and amount of nitrogen deposited by atmospheric deposition.

Precision farming addresses this complex problem by providing real-time variable-rate fertilizer application that takes into consideration the crop, soil type, soil fertility, and other factors within an individual field. This maximizes the efficiency of fertilizer application, minimizes waste, and reduces surface water contamination. On a larger scale, the management guidelines of statewide fertilizer use for a given crop can be adjusted for the spatial variation of plant-available atmospheric nitrogen deposition. For instance, precipitation over the Midwest annually contributes 3 to 7 kilograms per hectare of inorganic nitrogen to the soil, representing less than 5% of the inorganic nitrogen needs of corn and up to 15% of the nitrogen needs of wheat, depending on the target yield of the crop and on soil quality. Estimated atmospheric nitrogen deposition for the eastern United States could account for at least 10% of the nitrogen needs of major, nonnitrogen-fixing crops.

All of us benefit as science and technology continue to work together to optimize farmland crop production and safeguard the water supply and terrestrial and aquatic ecosystems.

ecosystems are more sensitive to added nitrogen than others: certain high-elevation eastern forests and streams, East and Gulf Coast estuaries, and western alpine areas and high-elevation forests.

What Effects Are Associated with Nitrogen Deposition?

Depending on the chemical form and amount in the environment, nitrogen can serve as a nutrient, enhancing growth and productivity, or as a toxin, causing ecological damage or harming human health. Scientists often refer to nitrogen as a macronutrient because plants and animals require it in relatively large proportions compared to other essential nutrients such as iron or copper.

Nitrogen needs vary, depending on the ecosystem and on the plant or animal species. Different life forms within the same ecosystem do not have the same nitrogen requirements.

Many ecosystems and crops are limited by the availability of nitrogen. That's why the advent of synthetic fertilizers earlier in the 20th century has been such a boon to agricultural productivity. That's also why atmospheric deposition of nitrogen in some ecosystems may stimulate unhealthy growth or cause growth of some plants at the expense of others.

Air quality and atmospheric deposition are closely linked. Nitrogen oxides contribute to the formation of ozone, a lung irritant. Many studies have shown that elevated ozone levels also damage plant leaves and reduce crop yields. Near urban or industrial air pollution sources, high nitrogen dioxide concentrations can irritate human lung tissues and lower resistance to influenza or other respiratory infections.

Visibility degradation and acidic deposition are also linked. Too many fine particles in the air create the unsightly haze that reduces visibility in many U.S. cities and even occasionally shrouds the beautiful vistas in national park and wilderness areas. These fine particles contain nitrogen compounds (nitrate, ammonium, or both) and other pollutants (sulfate and carbon compounds). Sulfate is often more important than nitrogen in degrading visibility, especially in the eastern United States. When sunlight is present, nitrogen dioxide gas may also contribute to degradation of visibility .

While precipitation cleans the air, rain and snow contain nitrates and sulfates, making them more acidic. Statues, monuments, and the exteriors of buildings are all subject to acid rain damage. Acidic precipitation also affects sensitive streams, lakes, and soils, which are easily altered by chemical inputs. Acidic precipitation can disturb the delicate balance in these sensitive ecosystems.

Bristlecone pines are among the oldest living organisms. Increases in the amount of nitrogen that reaches this tree may reduce its chances of survival in such a harsh environment.

PHOTO BY GARY LEAR

Nitrogen deposition also may have a fertilizer effect. In estuaries and coastal ecosystems, this can lead to eutrophication, a condition characterized by algae blooms, low dissolved oxygen, and loss of invertebrates, fish, and other wildlife.

Effects on Freshwater and Terrestrial Systems

Freshwater streams, ponds, and lakes respond to the water and chemical inputs from rainstorms and snowmelt. On rare occasions when the ground is frozen, some headwater streams carry a surge of nitrate, sulfate, and acidity provided directly by rain or melting snow.

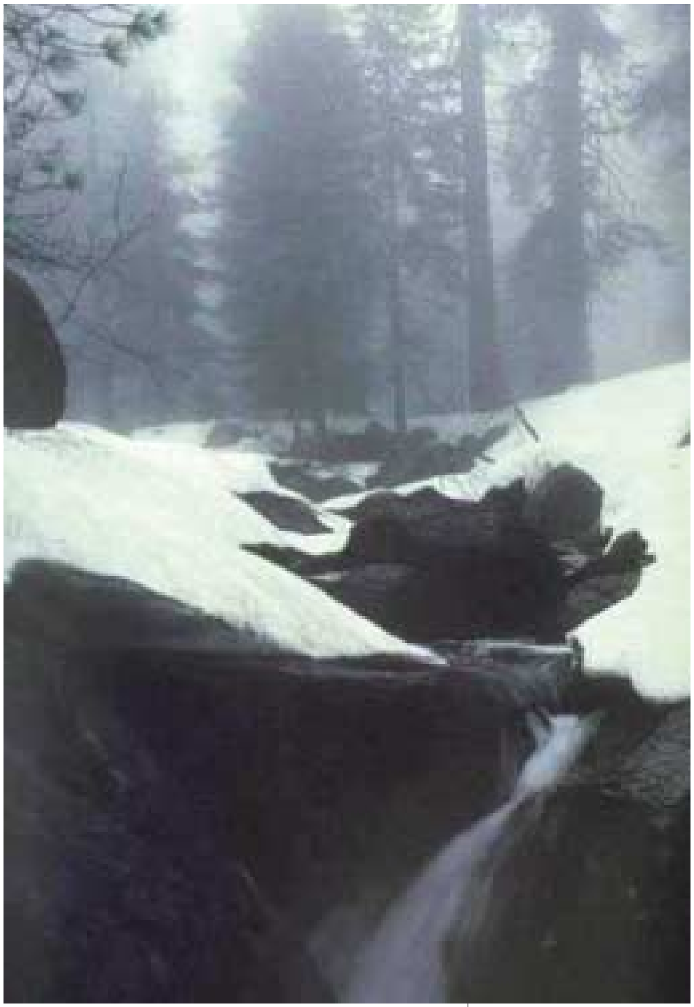
More typically, precipitation soaks into the ground adding nitrate and ammonium to the nitrogen cycle, which also involves soils, decaying plant and animal matter, microbes, and living plant roots. Many factors control the rate at which nitrogen enters and leaves this complex cycle, including soil type, temperature, microbial activity, and plant needs. Precipitation is just one source of the nitrogen in soils.

Scientists have found that the cumulative effect of years of nitrogen deposition does increase the amount of nitrogen carried by streamflow from some watersheds. Rainstorms and snowmelt can flush accumulated nitrate from soils into these streams.

Nitrogen deposition, especially in combination with sulfate, can contribute to episodic acidification of streams. Not all aquatic organisms have the same tolerance for these episodes, which can cause a decline in acid-sensitive fish, amphibian, and invertebrate populations.

Nitrogen deposition to forest and alpine soils can affect plant populations and overall forest health. Decades of acidic nitrate and sulfate deposition has depleted the supply of calcium and mobilized aluminum in some forest soils. Calcium is essential for tree growth, but aluminum interferes with the uptake of this nutrient by tree roots.

Low soil calcium has been linked to the dieback of sugar maples in some northeastern forests. Researchers are studying nitrogen-saturated, high-elevation spruce/fir forests in the Great Smoky Mountains National Park. They find that as aluminum in soil water increases, the calcium in spruce trees decreases,



Stream-water nitrogen often reaches a peak during the spring when snowmelt or rainstorms can flush nitrate from the soils.

Stream acidification in Shenandoah National Park has had effects on some native species, such as this brook trout.

PHOTO BY KATHY TONNESSEN

possibly making trees more vulnerable to drought and insect infestations.

Experiments have shown that adding nitrogen to alpine forest and grass communities alters the species mix. Those plants that can store and use the added nitrogen become predominant.

Effects on Estuarine Systems

The numerous estuaries along the U.S. coastline have great economic, aesthetic, and ecological value. Watersheds collect water and direct its flow into estuaries and other water bodies. Atmospheric deposition delivers nitrogen to estuaries and their watersheds. Nitrogen from many sources enters an estuary; only a portion is from atmospheric deposition (see sidebar on Chesapeake Bay). Estuary and watershed size are important in evaluating the atmospheric contribution to the total nitrogen entering an estuary.

Soils, plants, and animals retain much of the nitrogen deposited in estuarine watersheds. Much of the remainder leaves these watersheds in runoff to streams and rivers. Subsurface water carrying nitrogen can also enter these waterways, which feed into estuaries.

Nitrogen has unique effects on individual estuaries. Along the East and Gulf Coasts, nitrogen promotes growth of algae. These microscopic waterborne plants cloud water and block sunlight, which can interfere with aquatic plant and animal productivity and affect water temperature and currents. For example, algae can inhibit growth of sea grasses that offer habitat for fish and shellfish.

While living algae can degrade habitat, decaying algae also can have effects as they complete their life cycle, sink to the bottom, and decompose. Decomposition of algae and other dead matter removes oxygen from bottom waters and can lead to hypoxia, a low-oxygen condition. Hypoxia has negative impacts on populations of bottom dwellers such as crabs, oysters, mussels, and clams.

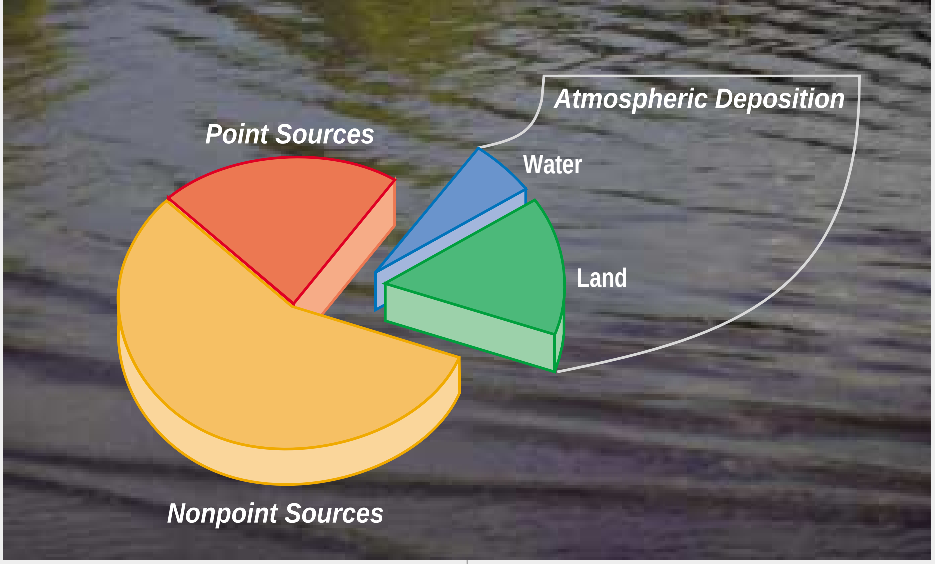
PHOTO BY KATHY TONNESSEN

Bioassays can assess the health of fish.

How is Nitrogen Deposition Measured?

Nitrogen deposition occurs as both wet and dry deposition. The National Atmospheric Deposition Program (NADP) National Trends Network (NTN) measures nitrate and ammonium in one-week rain and snow samples at nearly 240 regionally representative sites in 48 states. Nitrate and ammonium are measured in daily samples at another 10 sites in NADP's Atmospheric Integrated Research Monitoring Network (AIRMoN). These two NADP networks measure the wet deposition of inorganic nitrogen (see NADP sidebar).

Two networks measure atmospheric concentrations of gaseous nitric acid and particulate ammonium and nitrate at rural locations across the United States. The U.S. Environmental Protection Agency Clean Air Status and Trends Network (CASTNet) operates 84 sites. The National Oceanic and Atmospheric Administration operates the 5 sites in the AIRMoN dry deposition program. Dry deposition rates are calculated using



Sources of nitrogen to the Chesapeake Bay.

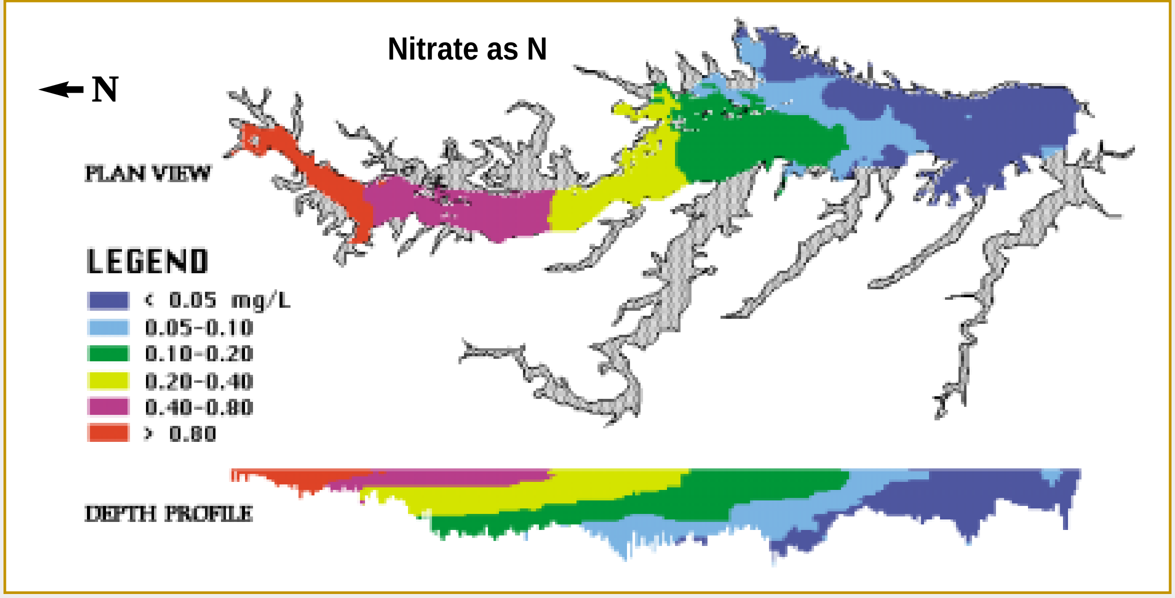
Source: Chesapeake Bay Program, *The State of the Chesapeake Bay,* CBP/TRS 222/108, October 1999.

The Chesapeake Bay

The Chesapeake Bay, located in coastal Maryland and Virginia, is the largest of 130 estuaries in the nation. The Bay's most troubling problem is an overabundance of nutrients. Excess nutrients lead to increased algal production and organic matter, a process known as eutrophication. Nitrate accumulates in the Bay during winter and spring. As temperatures rise, this nitrate promotes excessive algal growth. By mid-summer the decay of algae and other dead matter lead to hypoxia in the bottom waters of the Bay (see "Effects on Estuarine Systems").

Researchers are using NADP data to compute the amount of nitrogen deposited by precipitation in Chesapeake Bay and its watershed. Scientists are using computer modeling to simulate the complex cycling of nitrogen through this terrestrial watershed, which has a far greater area than the Bay itself. Chesapeake Bay Program models were used to estimate the contributions of the primary sources of nitrogen to the Bay (see pie chart).

The Chesapeake Bay Program seeks ways to reduce the amount of nitrogen entering the Bay (see map). High-quality data from NADP measurements give cooperating scientists and policymakers the information they need to meet this goal.

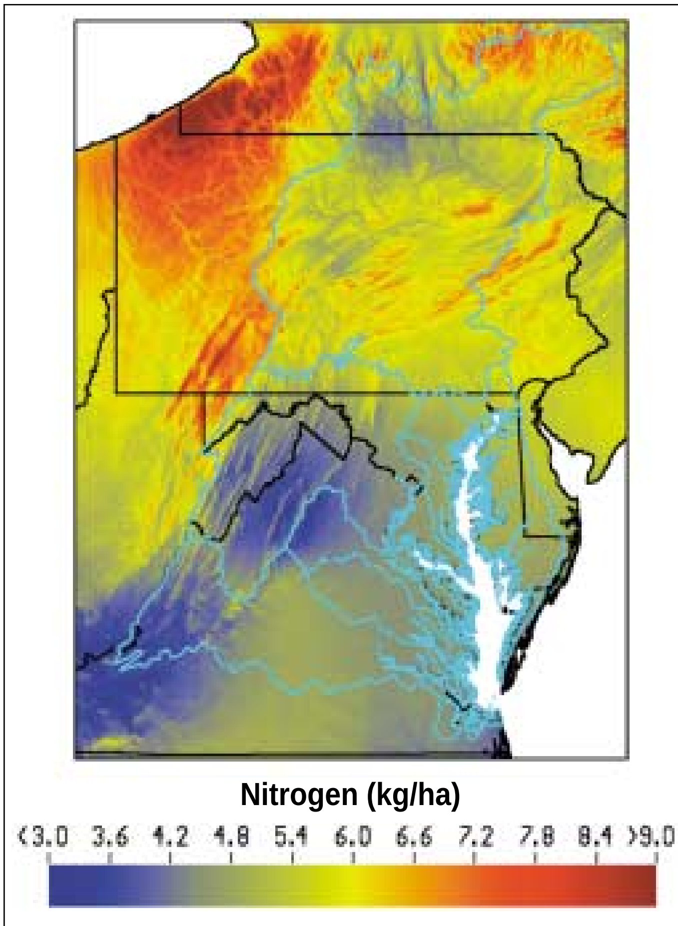


A water quality analysis of nitrate as N in the Chesapeake Bay.

Source: Chesapeake Bay Program.

these concentration data and deposition velocities simulated by a computer model. The model uses meteorological measurements, and information on land use, vegetation, and surface conditions. Calculating the dry deposition of inorganic nitrogen requires summing the individual rates for nitric acid, nitrate, and ammonium.

The amount of nitrogen deposited by precipitation can be calculated for locations without NTN or AIRMoN sites. One approach uses NADP rainfall, nitrate and ammonium concentration data, and digital terrain maps. These maps make it possible to generate plots that account for terrain effects on wet deposition. The map generated for the Chesapeake Bay watershed using this technique includes important information for planners, policymakers, and the scientific community about the complex relationship between the atmosphere and the ecological health of the nation's estuarine systems.



Estimated 1997 wet deposition of nitrogen in the Chesapeake Bay watershed.
Source: J. W. Grimm and J. A. Lynch, Pennsylvania State University.

Summary

Nitrogen is a macronutrient that is essential for all living things. Fossil fuel combustion, animal husbandry practices, nitrogen fertilizer production and application, and other human activities add substantial amounts of nitrogen compounds to the atmosphere every year. Higher airborne nitrate and ammonium concentrations from these activities increase the wet and dry deposition rates of nitrogen. Increased atmospheric deposition can affect natural and agricultural systems.

Information on nitrogen deposition, such as that collected by the NADP, is important to regulators, policymakers, and land managers responsible for the protection of air and water quality in natural and managed ecosystems.

A headwater stream.

About the National Atmospheric Deposition Program

Evaluating nitrogen deposition from the atmosphere is a major role of the National Atmospheric Deposition Program (NADP) — a partnership of State Agricultural Experiment Stations, federal, state, and local government agencies, universities, public institutions, Native American organizations, and industries. Continued commitments by these organizations make it possible for NADP to provide the only long-term record of precipitation chemistry in the United States. This information is used by scientists, policymakers, and the public in addressing the health, environmental, and agricultural issues facing the nation, including policy decisions related to the Clean Air Act amendments.

NADP was initiated in 1977 to address the problem of atmospheric deposition and its effects on agricultural crops, forests, rangelands, surface waters, and other natural resources. NADP coordinates approximately 240 sites in the National Trends Network, which collects weekly precipitation samples for chemical analysis. Samples are analyzed at the program's Central Analytical Laboratory in Champaign, Illinois, to determine the amounts of certain chemicals, including nitrate and ammonium.

Two additional networks joined NADP in the 1990s: the Atmospheric Integrated Research Monitoring Network (AIRMoN) in 1992 and the Mercury Deposition Network (MDN) in 1996. The AIRMoN wet deposition program evaluates the effect of emission changes on precipitation chemistry, combining measurements with atmospheric models. MDN is investigating the importance of atmospheric deposition as a source of mercury in lakes and streams.

A number of federal agencies support NADP, including the Tennessee Valley Authority; U.S. Department of Agriculture (Cooperative State Research, Education, and Extension Service, and Forest Service); U.S. Department of Commerce (National Oceanic and Atmospheric Administration); U.S. Department of Interior (Bureau of Land Management, National Park Service, U.S. Fish & Wildlife Service, and U.S. Geological Survey); and U.S. Environmental Protection Agency. Additional support comes from various other federal agencies, State Agricultural Experiment Stations, state and local government agencies, universities, Native American organizations, and public and private research organizations.

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NATIONAL ATMOSPHERIC DEPOSITION PROGRAM
A Cooperative Research Support Program of the
State Agricultural Experiment Stations (NRSP-3)
Federal and State Agencies
and Private Research Organizations

ILLINOIS
DEPARTMENT OF
NATURAL
RESOURCES

The Illinois State Water Survey is an Affiliated Agency of the University of Illinois and a Division of the Illinois Department of Natural Resources.

Key Terms

Ammonia/Ammonium
Compounds of nitrogen and hydrogen that readily dissolve in water. In oxygen-rich water, ammonium is easily transformed to nitrate and in oxygen-poor water to molecular nitrogen. Ammonium and nitrate comprise most of the inorganic nitrogen in precipitation.

Atmospheric Deposition
The process whereby airborne particles and gases are deposited on the earth's surface by wet deposition (precipitation) or by dry deposition (processes such as settling, impaction, and adsorption).

Dry Deposition
Atmospheric deposition that occurs when particles settle to a surface, collide with and attach to a surface, or when gases stick to a surface (adsorption) or are absorbed.

Estuary
An arm of the sea at the mouth of a stream or river where freshwater and salt water meet.

Eutrophication
A process in which nutrients degrade water quality due to excessive growth of microscopic plants and animals. As this matter dies and decays, it sometimes removes so much dissolved oxygen from the water that fish and other organisms cannot survive.

Hypoxia
A low-oxygen condition whereby decaying microscopic plants and animals in estuarine waters remove oxygen to a level below which most aquatic animals can survive. Although fish and shrimp can migrate from hypoxic zones, less mobile bottom dwellers cannot.

Nitrate
A compound of nitrogen and oxygen that is highly soluble in water. Nitrate is stable over a wide range of environmental conditions and is readily transported in surface and ground water.

Nitrogen
Molecular nitrogen (N_2), an extremely stable gas, comprises 78% of the atmosphere. Converting this gas to other chemical compounds requires lots of energy. Other compounds of nitrogen include nitrate and ammonia/ammonium.

Watershed
A land surface from which water drains to a lake, stream, river, estuary, or bay.

Wet Deposition
Atmospheric deposition that occurs when rain, snow, or fog carry gases and particles to the earth's surface.

Resources

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Web Site Resources

Web Site Resources

Chesapeake Bay Program: www.chesapeakebay.net

Ecological Society of America: www.esa.org

National Acid Precipitation Assessment Program: www.oar.noaa.gov/organization/napap.html

National Atmospheric Deposition Program: nadp.sws.uiuc.edu

National Oceanic and Atmospheric Administration AIRMoN Dry Deposition Program: www.arl.noaa.gov/research/projects/airmon_dry.html

National Park Service Air Resources Division: www2.nature.nps.gov/ard

U.S. Environmental Protection Agency

- **Clean Air Status and Trends Network**: www.epa.gov/castnet
- **Environmental Monitoring and Assessment Program**: www.epa.gov/emap
- **Gulf of Mexico Program**: pelican.gmpo.gov
- **National Estuary Program**: www.epa.gov/nep
- **Office of Air & Radiation**: www.epa.gov/oar

U.S. Geological Survey Acid Rain Program: bqs.usgs.gov/acidrain/index.htm

NADP Cooperators

State Agricultural Experiment Stations

Auburn Univ.-Black Belt Substa.; Auburn Univ.-Sand Mtn. Substa.; Colorado State Univ.-Central Plains Experimental Range; Cornell Univ.-Aurora Res. Farm; Iowa State Univ.-McNay Res. & Demonstration Farm; Kansas State Univ.-Konza Prairie; Louisiana State Univ.-Iberia Res. Sta.; Louisiana State Univ.-Southeast Res. Sta.; Montana State Univ.-Northern Ag. Res. Ctr.; North Carolina State Univ.-Finley Farm; North Carolina State Univ.-Horticultural Crops Res. Sta.; North Carolina State Univ.-Peanut Belt Res. Sta.; North Carolina State Univ.-Piedmont Res. Sta.; Ohio State Univ.-Eastern Ohio R&D Ctr.; Ohio State Univ.-Ohio Ag. R&D Ctr.; Oklahoma State Univ.-Goodwell Res. Sta.; Oregon State Univ.-Hyslop Farm; Pennsylvania State Univ.-School of Forest Resources; Pennsylvania State Univ.-Fruit Res. & Extension Ctr.; Purdue Univ.-Purdue Ag. Res. Ctr.; Purdue Univ.-Southwest-Purdue Ag. Ctr.; South Dakota State Univ.-Cottonwood Range Livestock Field Sta.; Texas A&M Univ.-Texas A&M Ag. Res. Sta.-Beeville; Texas A&M Univ.-Texas A&M Ag. Res. Sta.-Sonora; Univ. of Arkansas-Ag. Res. & Extension Ctr.; Univ. of California-Davis; Univ. of California-Hopland Field Sta.; Univ. of Florida-Bradford Forest; Univ. of Georgia-Coastal Plain Exp. Sta.; Univ. of Georgia-Georgia Exp. Sta.; Univ. of Illinois-Dixon Springs Ag. Ctr.; Univ. of Illinois-Northern Illinois Agron. Res. Ctr.; Univ. of Illinois-Northwestern Illinois Ag. Res. & Demonstration Ctr.; Univ. of Maine-Greenville Sta.; Univ. of Maryland-Wye Res. & Education Ctr.; Univ. of Massachusetts-Suburban Exp. Sta.; Univ. of Michigan-Biological Sta.; Univ. of Michigan-Kellogg Biological Sta.; Univ. of Minnesota-Southwest Res. & Outreach Ctr.; Univ. of Missouri-Baskett Wildlife Area; Univ. of Missouri-Univ. Forest; Univ. of Nebraska-Ag. R&D Ctr.; Univ. of Nebraska-North Platte Ag. Exp. Sta.; Univ. of Vermont-Proctor Maple Res. Ctr.; Univ. of Wisconsin-Spooner Ag. Res. Sta.; Utah State Univ.-Utah Ag. Exp. Sta.; Virginia Polytechnic Inst. & State Univ.-Horton Res. Ctr.; Washington State Univ.-Palouse Conservation Farm

Universities

Alfred Univ.; Colorado State Univ.; Cornell Univ.; Eastern Kentucky Univ.; Miami Univ. of Ohio; Murray State Univ.; New Mexico State Univ.; North Carolina State Univ.-Southern Oxidant Study; Pennsylvania State Univ.; State Univ. of New York-Albany; State Univ. of New York-Fredonia; State Univ. of New York-Oswego; State Univ. of New York-Syracuse; Texas A&M Univ.; Univ. of Alaska, Fairbanks-Water & Environmental Res. Ctr.; Univ. of Arkansas-Monticello; Univ. of Colorado-Inst. of Arctic & Alpine Res.; Univ. of Delaware; Univ. of Kentucky-Ctr. for Applied Energy Res.; Univ. of Massachusetts; Univ. of Michigan-Biological Sta.; Univ. of Minnesota; Univ. of Missouri; Univ. of New Hampshire; Univ. of Oklahoma; Univ. of Puerto Rico; Univ. of South Carolina-Baruch Inst. for Marine Biology & Coastal Res.; Univ. of Vermont; Univ. of Virginia; Washington Univ.-Tyson Res. Ctr.

United States Government Agencies

National Aeronautics & Space Admin.; National Science Foundation-Long-Term Ecological Res. Program; Tennessee Valley Authority; U.S. Dept. of Agriculture *(Ag. Res. Service, Cooperative State Res. Education & Extension Service, Science & Education Admin.)*; U.S. Dept. of Agriculture/Forest Service *(Wildlife, Fish, Water & Air Res., Bitterroot Nat'l Forest, Bridger-Teton Nat'l Forest, Coweeta Hydrologic Lab., Forest Sciences Lab.-Delaware, Ohio, Fremont Nat'l Forest, Gifford Pinchot Inst. for Conservation Studies, Hiawatha Nat'l Forest, H.J. Andrews Experimental Forest, Hubbard Brook Experimental Forest, Huron-Manistee Nat'l Forest, Kane Experimental Forest, Medicine Bow-Routt Nat'l Forest, North Central Res. Sta., Northeastern Res. Sta., Pacific Northwest Res. Sta., Pacific Southwest Res. Sta., Rocky Mtn. Res. Sta., San Juan Nat'l Forest, Shoshone Nat'l Forest, Southern Res. Sta., Superior Nat'l Forest, White River Nat'l Forest)*; U.S. Dept. of Commerce/National Oceanic & Atmospheric Admin. *(Air Resources Lab., Atmospheric Turbulence & Diffusion Div., Nat'l Weather Service)*; U.S. Dept. of Defense/U.S. Military Academy; U.S. Dept. of Energy *(Argonne Nat'l Lab., Los Alamos Nat'l Lab., Nat'l Energy Tech. Lab., Oak Ridge Nat'l Lab.)*; U.S. Dept. of Interior/Bureau of Land Mgt. *(Nat'l Applied Resource Sciences Ctr., Lander Field Ofc.-Wyoming, Las Vegas Field Ofc.-Nevada, Little Snake Field Ofc.-Colorado, Safford Field Ofc.-Arizona)*; U.S. Dept. of Interior/Bureau of Reclamation; U.S. Dept. of Interior/National Park Service *(Air Resources Div., Acadia Nat'l Park, Allegheny Portage Railroad Nat'l Historic Site, Assateague Island Nat'l Seashore, Bandelier Nat'l Monument, Big Bend Nat'l Park, Bryce Canyon Nat'l Park, Buffalo Nat'l River, Canyonlands Nat'l Park, Cape Cod Nat'l Seashore, Capulin Volcano Nat'l Monument, Chiricahua Nat'l Monument, Craters of the Moon Nat'l Monument, Death Valley Nat'l Park, Denali Nat'l Park, Everglades Nat'l Park, Glacier Nat'l Park, Grand Canyon Nat'l Park, Great Basin Nat'l Park, Great Smoky Mtns. Nat'l Park, Guadalupe Mtn. Nat'l Park, Hawaii Volcanoes Nat'l Park, Indiana Dunes Nat'l Lakeshore, Isle Royale Nat'l Park, Joshua Tree Nat'l Park, Lassen Volcanic Nat'l Park, Little Big Horn Battlefield Nat'l Monument, Mesa Verde Nat'l Park, Mt. Rainier Nat'l Park, North Cascades Nat'l Park, Olympic Nat'l Park, Organ Pipe Cactus Nat'l Monument, Pinnacles Nat'l Monument, Rocky Mtn. Nat'l Park, Sequoia Nat'l Park, Shenandoah Nat'l Park, Theodore Roosevelt Nat'l Park, Valley Forge Nat'l Historical Park, Virgin Islands Nat'l Park, Voyageurs Nat'l Park, Yellowstone Nat'l Park, Yosemite Nat'l Park)*; U.S. Dept. of Interior/U.S. Fish & Wildlife Service *(Air Quality Branch, Attwater Prairie Chicken Nat'l Wildlife Refuge, Cape Romain Nat'l Wildlife Refuge, Chassahowitzka Nat'l Wildlife Refuge, Edwin B. Forsythe Nat'l Wildlife Refuge, Hatchie Nat'l Wildlife Refuge, Mingo Nat'l Wildlife Refuge, Muleshoe Nat'l Wildlife Refuge, Okefenokee Nat'l Wildlife Refuge, Salt Plains Nat'l Wildlife Refuge, Santee Nat'l Wildlife Refuge, Seney Nat'l Wildlife Refuge)*; U.S. Dept. of Interior/U.S. Geological Survey; U.S. Environmental Protection Agency *(Ofc. of Air & Radiation-Clean Air Markets Div., Ofc. of Wetlands, Oceans, and Watersheds, Nat'l Health & Environmental Effects Res. Lab.-Western Ecology Div.)*

State & Local Government Agencies

Alabama Dept. of Environmental Mgt.; Arkansas Dept. of Environmental Quality; Delaware Dept. of Natural Resources & Environmental Conservation Trap Pond State Park; Florida Dept. of Environmental Protection; Fort Worth, Texas, Dept. of Environmental Mgt.; Illinois State Water Survey; Indiana Dept. of Environmental Mgt.; Iowa Conservation Commission; Kansas Dept. of Wildlife & Parks; Louisiana Dept. of Environmental Quality; Maine Dept. of Environmental Protection; Maryland Dept. of Natural Resources; Massachusetts Dept. of Environmental Protection; Minnesota Pollution Control Agency; Missouri Dept. of Natural Resources; New Hampshire Dept. of Environmental Services; New Jersey Dept. of Environmental Protection; New Mexico Environment Dept.; North Carolina Dept. of Environment, Health, & Natural Resources; North Dakota State Parks & Recreation-Icelandic State Park; Northeast States for Coordinated Air Use Mgt.; Oklahoma Conservation Commission; Pennsylvania Dept. of Conservation & Natural Resources; Pennsylvania Dept. of Environmental Resources; Portland, Oregon, Water Bureau; San Francisco Estuary Inst.; San Jose Environmental Services Dept.; Siskiyou County, California-Air Pollution Control Dist.; South Carolina Dept. of Health & Environmental Control; South Carolina Dept. of Natural Resources; South Florida Water Mgt. Dist.; St. Johns River Water Mgt. Dist.; Texas Natural Resource Conservation Commission; Vermont Dept. of Environmental Conservation; Wisconsin Dept. of Natural Resources

Industry

Advance Tech. Systems, Inc.; Atmospheric Res. & Analysis, Inc.; BP Amoco; Constellation Energy Group; Dynamac Corp.; Exxon Mobil Corp.; Florida Power & Light Co.; Frontier Geosciences, Inc.; Harding ESE, Inc.; Lockheed Martin Energy Res.; SF Phosphates, Ltd.; Southern Company; Union Camp Corp.; Westinghouse Savannah River Co.

Native American Tribes and Organizations

Fond du Lac Reservation; Fort Peck Tribes; Grand Traverse Band; Lac Courte Oreilles Tribe; Menominee Indian Tribe; Mille Lacs Band of Ojibwe; Penobscot Nation; St. Regis Mohawk Tribe

Other Research Organizations

Black Rock Forest Inst.; Electric Power Res. Inst.; Environment Canada-Atmospheric Environment Branch; Environment Canada-Air Quality Res. Branch; Environment Canada-Environmental Conservation Service; Environment Canada-Meteorological Service of Canada; Green River High School, Utah; Huntsman Marine Science Centre, Canada; Ministere de l'Environnement du Quebec; New Brunswick Dept. of Environment; North Woods Audubon Nature Ctr., Minnesota; Wolf Ridge Environmental Learning Ctr., Minnesota