EPA

Nitrogen: Multiple and Regional Impacts

United States
Environmental Protection
Agency

Clean Air
Market Programs

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Introduction

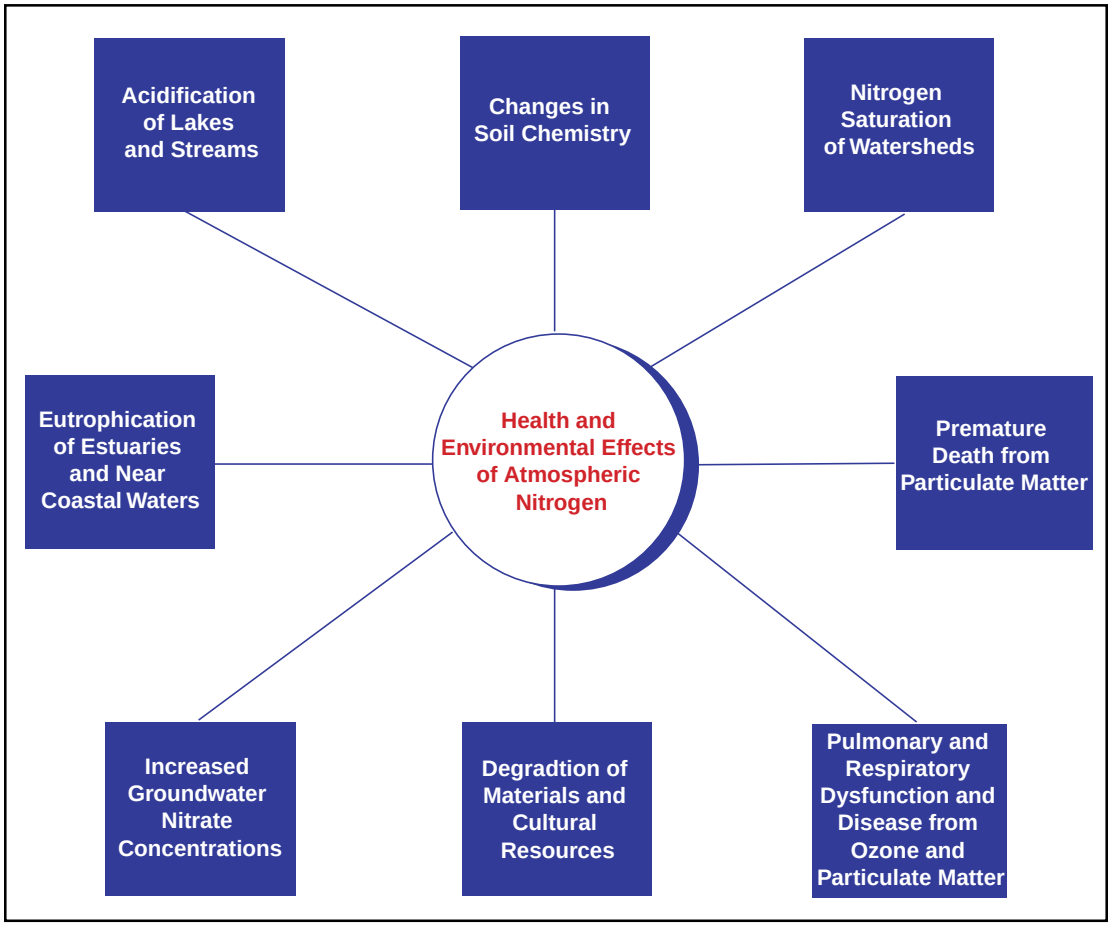
Nitrogen,[1] the most abundant element in the air[2] we breathe, is essential to plant and animal life. Historically, this airborne compound has persisted in a state of equilibrium as part of a *nitrogen cycle* embracing air, water, plants, animals, and soils. However, human inputs from electric power generation, industrial activity, transportation, and agriculture have disrupted this balance. These sources have released unprecedented quantities of nitrogen and related compounds to the environment in the past 50 years. Other than nitrogen gas (N_2), the two primary categories into which most nitrogen compounds fall are reduced nitrogen, typically dominated by ammonia species (e.g., NH_3 and NH_4^+), and oxidized nitrogen, composed primarily of *nitrogen oxides (NO_X)*. Of these two categories of nitrogen compounds, oxidized nitrogen sources are subject to a variety of regulations that limit emissions. On the other hand, sources of reduced nitrogen remain largely unregulated. While this document discusses certain sources and issues with regard to reduced nitrogen, it focuses primarily on atmospheric emissions, deposition, and impacts of oxidized nitrogen (NO_X emissions).

Nitrogen emissions can affect human health in various ways. Nitrogen dioxide (NO_2) is irritating to human lungs, and aids in the formation of *particulate matter* and *ozone*. These airborne byproducts of nitrogen emissions can cause premature mortality and chronic respiratory illness such as bronchitis or asthma, as well as aggravate existing respiratory illness. While less directly linked to atmospheric emissions, *nitrate* contamination of drinking water supplies, largely from agricultural sources, can result in *methemoglobinemia* or Blue Baby Syndrome.

Nitrogen oxides also contribute to a range of environmental effects including the formation of acid rain, changes in plant and animal life in some ecosystems, and reduced visibility. We have already seen the impacts that increased nitrogen levels can have across the United States. Certain forests outside Los Angeles experience reduced growth rates, grasslands in the Midwest suffered a loss of species diversity, streams in Virginia are too acidic to support trout populations, *estuaries* such as Long Island Sound and Chesapeake Bay experience noxious algal blooms, and visibility in many national parks has diminished to the extent that it is nearly impossible to see some of our nation's most scenic natural wonders.

[1] Throughout the report, terms that are defined in the Glossary at the end of the document, will be *italicized* the first time they appear in the report

[2] Nitrogen gas (N_2) makes up 78 percent of the atmosphere.



Need For a Regional Approach

The U.S. Environmental Protection Agency has a long history of addressing and assessing the impacts of nitrogen emissions. For example, a series of actions including the implementation of *National Ambient Air Quality Standards (NAAQS)* affecting both mobile and stationary sources and NO_X reduction under the Acid Rain Program have achieved significant reductions in NO_X emissions. Additional actions scheduled for implementation in future years will further reduce NO_X emissions from stationary and mobile sources. The EPA also undertakes significant efforts to assess the results of past policies and evaluate the need for future actions to reduce NO_X emissions. Such assessment efforts require an understanding of the various sources from which nitrogen enters the environment; the multiple pathways by which nitrogen moves through the environment; and the effects on human health, ecosystems, and materials that result from exposure to nitrogen-related compounds. This document details actions undertaken to reduce NO_X emissions, as well as efforts to assess the results of those actions, and briefly describes the need for further NO_X emission reduction efforts (see pages 22-30).

Once nitrogen compounds are released into the environment, they can travel hundreds of miles from their sources, affecting remote communities and resources downwind. This phenomenon

can be seen in the acidification of lakes and streams in the Adirondack region of New York State and in other eastern areas. These regions are downwind of the Ohio River Valley and the growing southeast, the locations of significant portions of the nation's power and metals industries and areas of increasing vehicle use, all of which represent major sources of emissions. Even when one state curtails its production of pollutants such as NO_x, emissions from other states still travel, cross state boundaries, and affect downwind regions. In addition, nitrogen pollution can enter aquatic environments as runoff from terrestrial systems or directly through *atmospheric deposition,* connecting atmospheric, terrestrial, freshwater, and estuarine systems. Thus, nitrogen pollution is truly a regional problem with human health and ecological impacts that not only occur at significant distances from the source of the pollution, but in a different environmental medium than the one into which the pollutant was originally emitted.

Since air pollutants do not recognize political boundaries, states and communities cannot independently solve all of their air pollution problems. Resolving air pollution control issues often requires state and local governments to work together to reduce air emissions. For example, the *Clean Air Act Amendments of 1990 (CAAA)* established the Ozone Transport Commission to develop regional strategies to address and control ground level ozone pollution in the northeastern U.S. The result of that CAAA provision, the Ozone Transport Commission NO_x Budget Program, has demonstrated promising results in reducing emissions with economic efficiency. In the years since passage of the 1990 CAAA, it has become clear to EPA and states that addressing the impacts from nitrogen emissions requires regional or national approaches, as state and local actions alone will be inadequate to solve the problems.

Structure of the Report

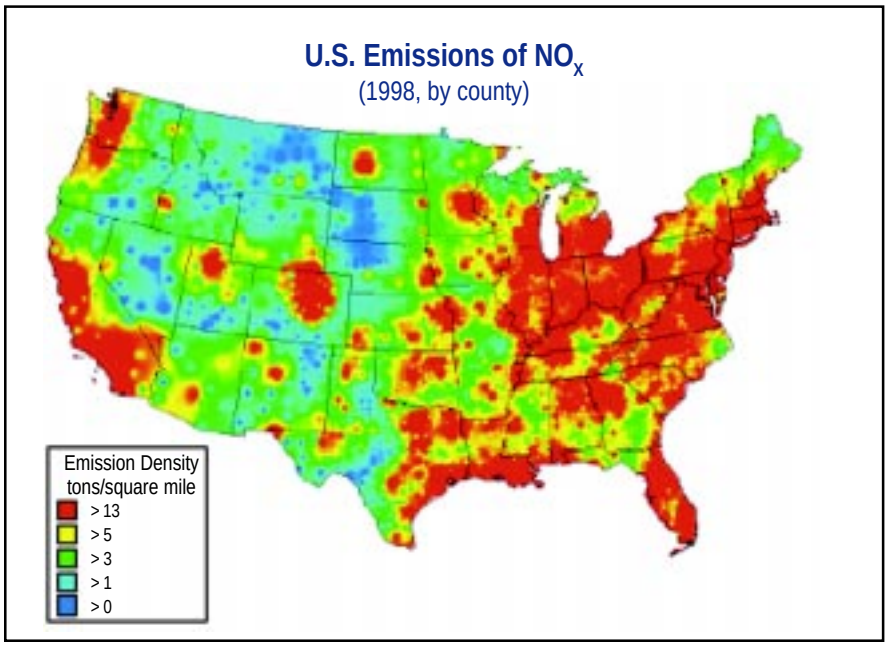
The release of nitrogen compounds into the environment is an important, multifaceted issue. This report is intended to assist an informed general audience in better understanding the many aspects and implications of nitrogen pollution. The report discusses EPA's current understanding of the causes of and impacts from excessive nitrogen emissions and deposition. It is organized according to the main areas of analysis noted above, with sections focused on nitrogen sources; multiple transport and exposure pathways; regional effects on human health, visibility and materials damages; regional ecological effects; and continuing efforts to reduce them.

Nitrogen Sources

Nitrogen gas is a naturally occurring compound integral to human and other life on the planet. While representing only a fraction of the total nitrogen found in the environment, the incremental levels of nitrogen resulting from human activities can have significant human and ecological health impacts. Since 1970, human activities have doubled the amount of nitrogen entering terrestrial, aquatic, and marine ecosystems. The most common nitrogen-related compounds emitted into the air by human activities are collectively referred to as nitrogen oxides, or NO_X, which represents primarily nitric oxide (NO) and nitrogen dioxide (NO_2). Both of these compounds are formed when oxygen gas (O_2) and N_2 are heated to very high temperatures. This can occur through both natural and man-made processes.

Natural Sources

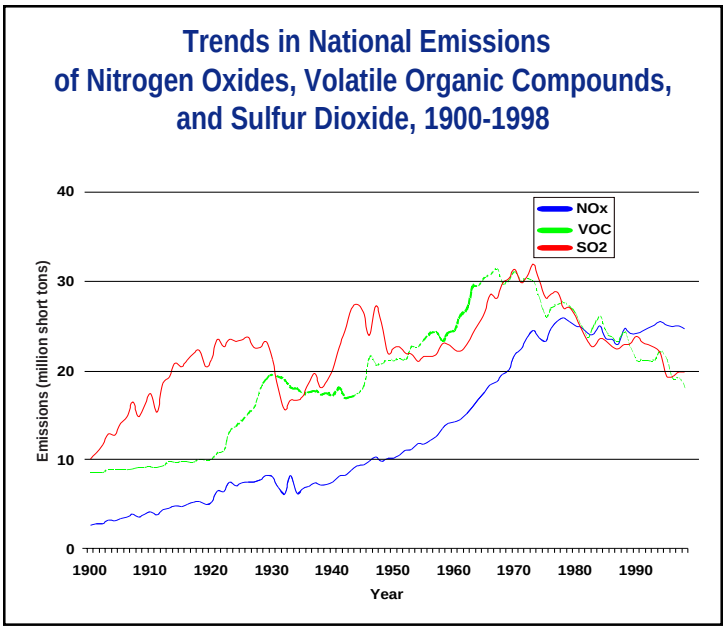
Natural events that generate extreme heat, primarily lightning, combine oxygen and nitrogen to form nitrogen oxide. Nitrogen from the atmosphere is also made available to plants and animals through a process called *biological nitrogen fixation*. Certain types of algae and bacteria are able to extract nitrogen from the air, making it usable by plants and, ultimately, all organisms that eat plants for nourishment. In the absence of man-made sources of nitrogen, most nitrogen pulled from the atmosphere by biological nitrogen fixation is re-emitted to the atmosphere through a process called *denitrification*. More importantly, little of the nitrogen from these natural sources moves from one environmental system to another (e.g., from forests to estuaries).



Man-made Sources

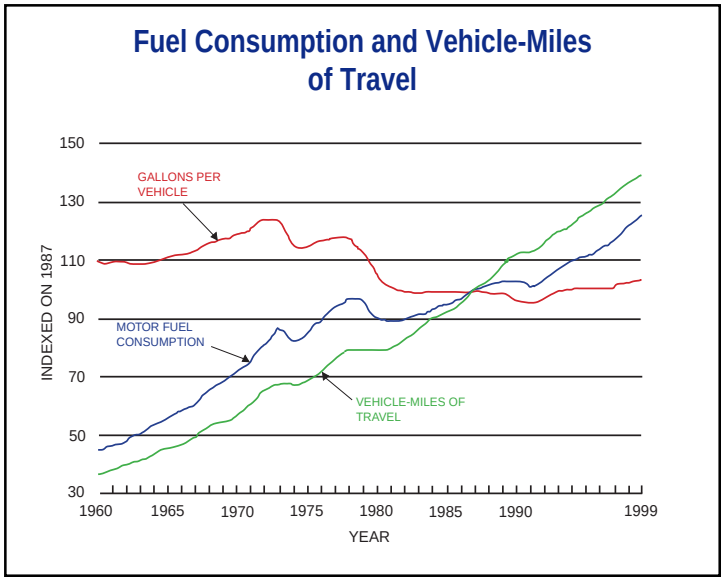
Burning of Fossil Fuels

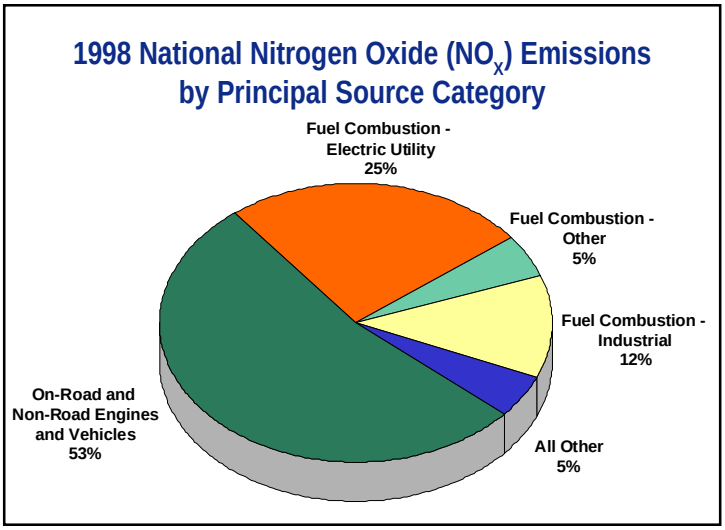
The combustion of fossil fuels, in engines used in transportation as well as in electric utility and industrial boilers, accounts for over 90 percent of the NO_X released in the U.S. due to human activity. While levels of most pollutants are declining, concentrations of nitrogen dioxide in the atmosphere have remained basically steady over the past decade as emissions of NO_X have increased by two percent. Regulatory requirements in the 1990 CAAA have improved the combustion process so that fewer contaminants are now released per unit of fuel burned than ever. Despite increasing stringency of combustion controls, increases in power generation and vehicle miles traveled will gradually offset these improvements. Without further regulatory actions or a cap, emissions are unlikely to decrease significantly.



Of the major sources of NO_X emissions, two categories predominate - large combustion units (including power generation and other heavy industry) and transportation-related sources (dominated by cars and trucks, but also including trains, ships, airplanes, and other non-road vehicles).

From 1988 to 1997, large, stationary utility and industrial burners accounted for roughly 10.5 to 11 million short tons, or approximately 45 percent, of the NO_X entering the U.S. atmosphere each year from human activities. EPA's Acid Rain program resulted in a 40 percent reduction in NO_X emission rates from large utility boilers and additional reductions due to summertime ozone con-



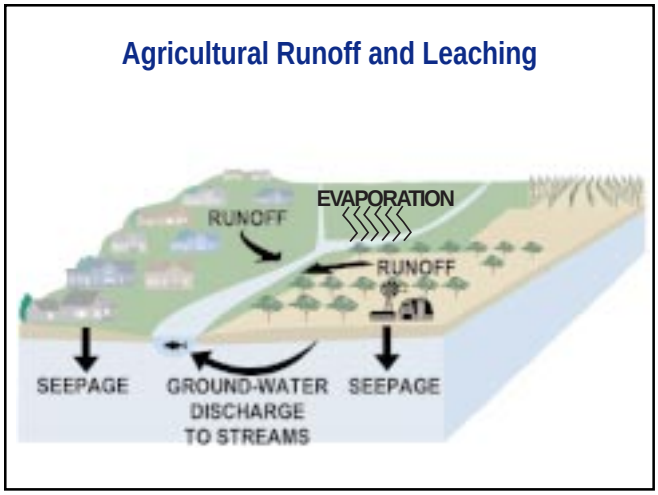


trols are expected over the next several years. However, increases in electricity production are expected to gradually erode the effect of these measures. In addition to stationary point sources, transportation-related sources have added between 11 and 12 million tons of NO_X to the atmosphere for each of the past 15 years, contributing 53 percent of all NO_X emissions. These emissions are concentrated in large urban areas and are a major component of urban *smog*. NO_X emissions from stationary and mobile sources will be reduced by various current and future regulations. These regulations are discussed further in this report under "Efforts to Understand and Reduce NO_X/ Nitrogen" (see p. 22).

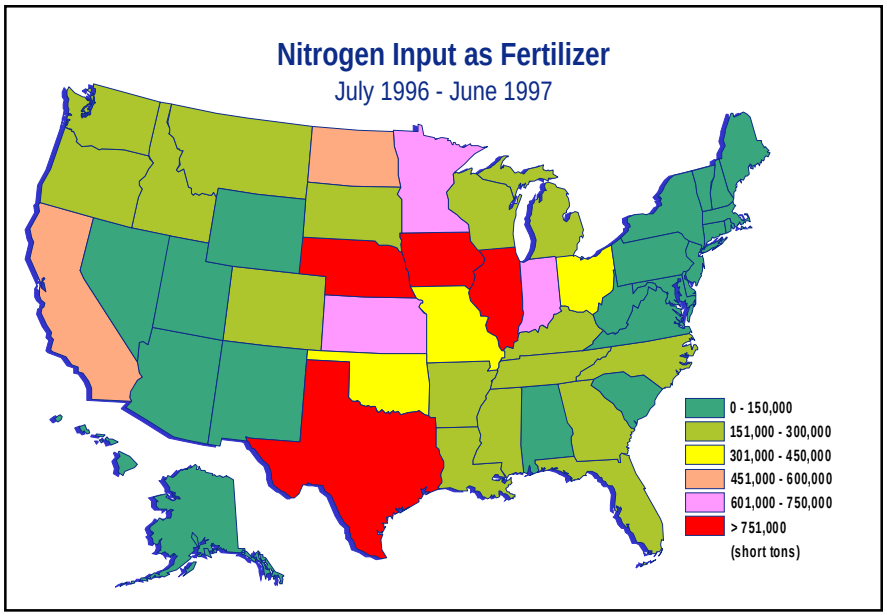
Agriculture

Nitrogen compounds added to the terrestrial environment from agricultural sources can also impact water and the atmosphere. In most cases, this nitrogen takes the form of ammonia or ammonium.

Farmers added 22 million tons of nutrients to American crops in 1997, more than half of which was nitrogen. This process increases crop productivity, especially as intensive cultivation depletes soil's natural nutrients. It can also cause excess nutrients from these *non-point sources* to wash into streams, rivers, and lakes. In addition, this nitrogen can seep or *leach* into local groundwater, potentially impacting the quality of drinking water.



Commercial feedlots, often containing large numbers of animals in a small area, also contribute significant quantities of nitrogen to local water supplies. As many animals are confined to a location over time, waste builds up and, if not treated properly, leaches into groundwa-

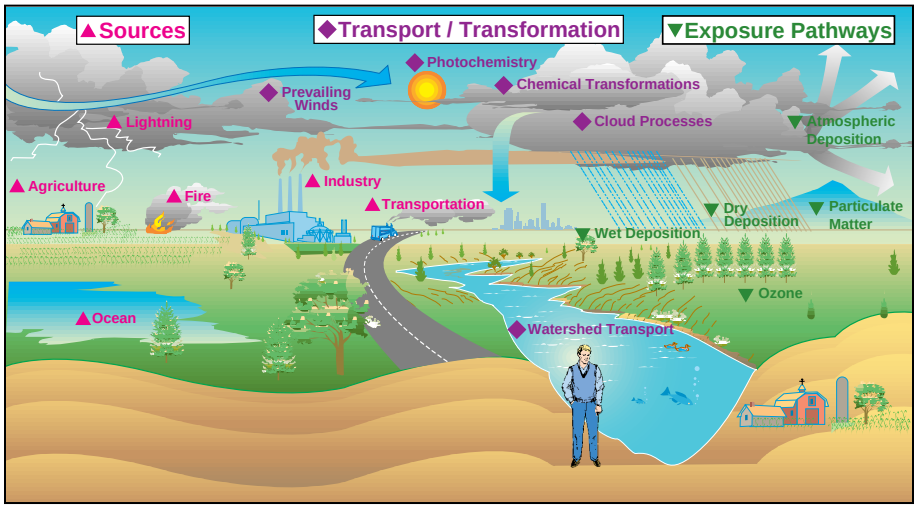


ter or runs off into streams. In 1997 alone, over a million tons of nitrogen leached into southeastern U.S. surface waters from manure, and surface waters in the south-central and north-central regions of the country received similar loadings.

In addition, agricultural operations can be an important source of atmospheric nitrogen. In 1998, for example, agriculture soil management accounted for 70 percent of emissions of nitrous oxide (N_2O), a powerful greenhouse gas that contributes to climate change. Evaporation from settling ponds used in treating waste from large animal feedlot operations can also contribute to airborne transport of nitrogen compounds, with local as well as broader impacts.

Multiple Transport and Exposure Pathways

Airborne nitrogen emissions reach soil and water resources as well as people, buildings, and other materials through multiple pathways. Ozone generation; production of particulate matter; and *wet, cloud, and dry deposition*; all contribute to the transport, exposure, and deposition of airborne nitrogen emissions. Airborne pollutants can travel hundreds of miles, affecting entire regions rather than just the area immediately surrounding a specific point or mobile source. In addition, nitrogen compounds also migrate once deposited into terrestrial or aquatic systems. When deposited onto land, for example, nitrogen compounds often leach into groundwater or migrate into surface water systems where they can move downstream affecting estuarine and coastal ecosystems.



The regional, transboundary nature of mobile air contaminants such as NO_X has challenged regulators for years. The geographic separation between cause and downwind effect has made it difficult to assign responsibility for specific damages to sources of contamination and reduces the immediate motivation of these sources to limit NO_X emissions. Recent petitions from downwind states in the eastern U.S. impacted by pollution have helped to stimulate action at the regional and national levels.

Human health impacts are associated with both chronic and acute concentrations of pollutants in the air that people breathe. Most ecological impacts result from the cumulative impacts of long-term deposition of atmospheric nitrogen onto terrestrial or aquatic systems.

Atmospheric Concentrations

Ozone

NO_X emissions can affect people and natural resources through the formation of ozone in the lower atmosphere. NO_X is key to the reaction that forms ozone, effectively producing many molecules of ozone for each NO_X molecule that is emitted. While ozone is a beneficial component of

the upper atmosphere, it is damaging to both ecological and human health when found in the lower atmosphere. Impacts on trees and plants include impairment of growth and commercial yield, reduction in the survival of seedlings, increase in susceptibility to disease and foul weather, and reduction in habitat quality for wildlife. These effects, as well as human health impacts associated with ozone such as respiratory problems, are discussed in more detail later in the report.

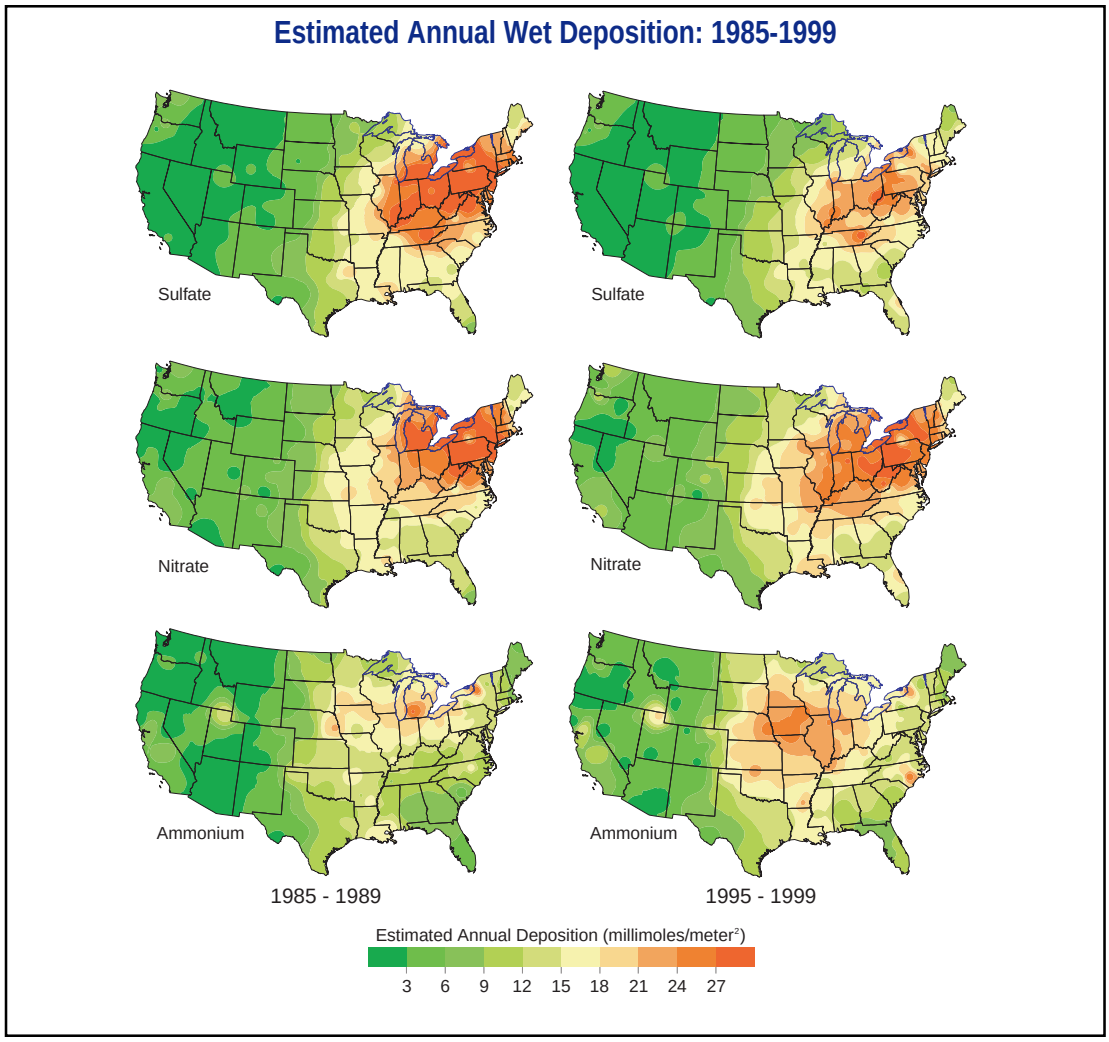
Particulate Matter

Nitrogen emissions also contribute to the formation of particulate matter. The term particulate matter (PM) refers to a combination of dust, soot, and solid and liquid masses that form in the atmosphere. Nitrogen oxides interact with other compounds to form the fine particles and droplets that constitute PM. While PM restricts visibility and contributes to haze problems, these particles are of greatest concern because of their impact on human health, contributing significantly to respiratory damage. Fine particles (defined as having a diameter of 2.5 microns (μm) or less, known as $PM_{2.5}$) are especially damaging as they penetrate deeper into lung tissue. As a result, EPA promulgated a new NAAQS for $PM_{2.5}$ in 1997 and is now monitoring levels of $PM_{2.5}$ as well as of coarse particulate matter (particles with a diameter of up to 10 μm, known as PM_{10}) in order to determine which areas of the country currently experience levels of exposure above these standards. By 2002, regulators will have sufficient data on $PM_{2.5}$ to determine which areas exceed these standards. Existing data indicate that ambient concentrations of PM_{10} decreased 26 percent between 1988 and 1997, but 70 counties in the U.S., primarily in western states, still do not meet PM_{10} standards. Another source of information for areas designated as non-attainment is the Green Book, located at http://www.epa.gov/oar/oaqps/greenbk.

Nitrogen Deposition

Wet Deposition

Wet deposition of sulfur and nitrogen compounds that contribute to acidification of lakes, streams, and soils is commonly known as acid rain, although such *acid deposition* also takes the form of snow, sleet, or hail. Certain nitrogen compounds interact with water vapor and droplets in the atmosphere so that the water becomes acidic. Wet deposition is intermittent, since acids only reach the earth when precipitation falls. Nevertheless, it can be the primary pathway for deposition of pollutants in areas that receive significant quantities of precipitation. In part because of the importance of climate in combination with emissions distributions, the eastern U.S. receives more



acidic precipitation than the rest of the country, with the greatest rates of deposition occurring in Ohio, West Virginia, western Pennsylvania, upstate New York, and other parts of the northeast. As the accompanying maps of wet deposition demonstrate, sulfate deposition has decreased in recent years while deposition of nitrate and ammonium have increased.

Wet deposition contributes to seasonal variation in nitrogen inputs to an ecosystem. When acidic or nitrogen-contaminated snow falls during the winter, many of the nitrogen compounds remain stored in the snow until it melts. Particularly in the northeast, large quantities of nitrogen compounds are suddenly released to the ecosystem as snow melts and heavy rains fall in the early spring. These surges can be especially damaging to fish and other resources, as described on page 18.

Water quality monitoring programs can miss dramatic seasonal variations in nitrogen inputs. The full toxicity that occurs during seasonal events is missed if samples are collected infrequently or if measurements of nitrogen levels are averaged over a year. Brief surges in nitrogen inputs such as those that occur during spring snowmelts and precipitation may reach levels that are four or five

times the average annual concentration, and thus have highly toxic impacts on organisms, sometimes resulting in fish kills. Even when annual data are averaged, overall trends in nitrogen concentrations still show an increase over the past 20 years. As levels of sulfate decrease, nitrogen compounds have become increasingly significant as contributors to long-term acidification.

Cloud Deposition

Acidic compounds can reach plants, soil, and water from contact with acidic clouds as well as from precipitation. While cloud deposition affects only a limited number of locations, it can provide a relatively steady source of nitrogen compounds and other acids in comparison with wet deposition. These conditions are most common at high altitudes, where clouds have been shown to contribute as much as 40 percent of total nitrogen inputs. Because high elevation ecosystems often have shallow topsoils, they are chemically less able to buffer the impacts of these inputs on sensitive alpine species. As a result, trees such as the red spruce have declined in areas of significant cloud deposition, including much of the southern Appalachian mountains.

Dry Deposition

Dry deposition is similar to the other pathways, but takes place when acidic gases and particles in the atmosphere are deposited directly onto surfaces when precipitation is not occurring. This process provides a more constant source of deposition than the other pathways. Dry deposition is therefore the primary acid deposition pathway in arid regions in the West. For example, areas such as the Joshua Tree National Park suffer significantly from dry deposition due in part to emissions from Los Angeles and the surrounding areas. The contribution of dry deposition to total deposition around the country ranges from 20 to 60 percent.

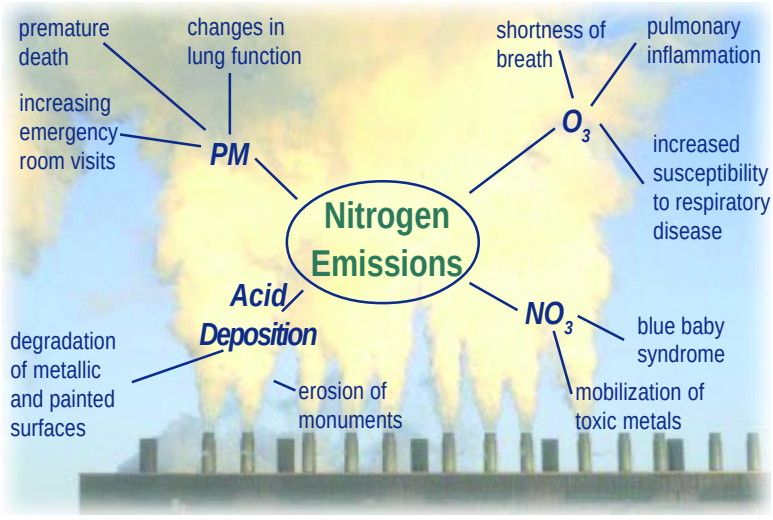
Regional Effects of Nitrogen Emissions on Health, Visibility & Materials

Airborne nitrogen compounds not only affect human health directly, but also contribute to the formation of other harmful air pollutants including smog and fine particles. Nitrogen oxides can inflict damage on the lungs at relatively low levels of exposure, and nitrogen emissions and their byproducts can limit visibility and damage buildings and other structures.

These impacts can be felt far from the geographic origin of the nitrogen. Pollutants can travel great distances and, when combined with volatile organic compounds in presence of sunlight, form ozone in areas far removed from their source.

Long-term exposure to NO_2 can cause lasting damage to the lungs and can increase susceptibility to respiratory infections. Young children, asthmatics, and the elderly are particularly sensitive to these conditions. Dangerous levels of NO_2 in the atmosphere are rare, however, as all areas in the U.S. currently meet NAAQS for NO_2. Accordingly, the most immediate effect on human health from nitrogen oxide emissions is indirect — through the production of particulate matter and ozone, which affect millions of people every year.

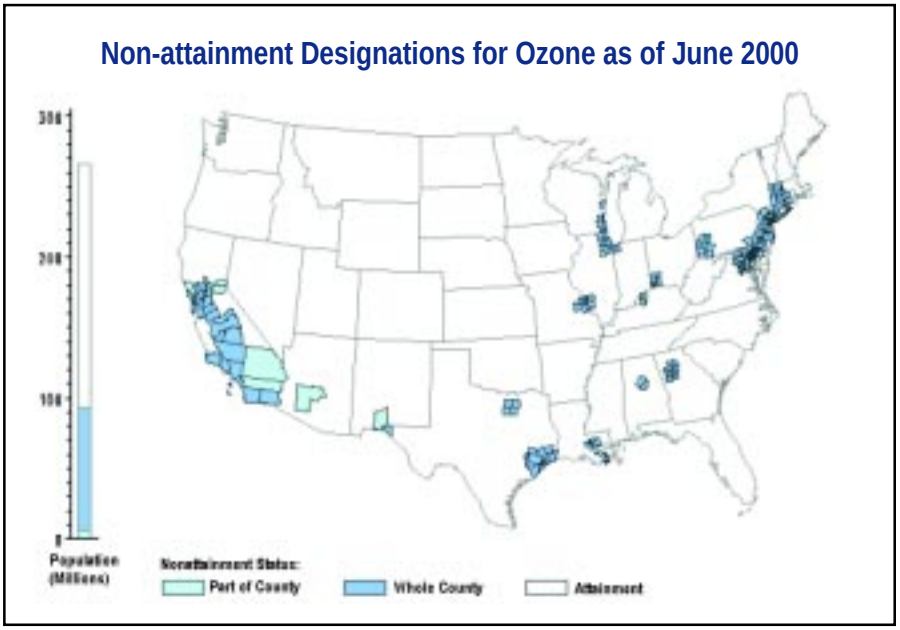
Human Health and Other Non-Ecosystem Effects of Nitrogen Compounds



Atmospheric Concentrations

Particulate Matter

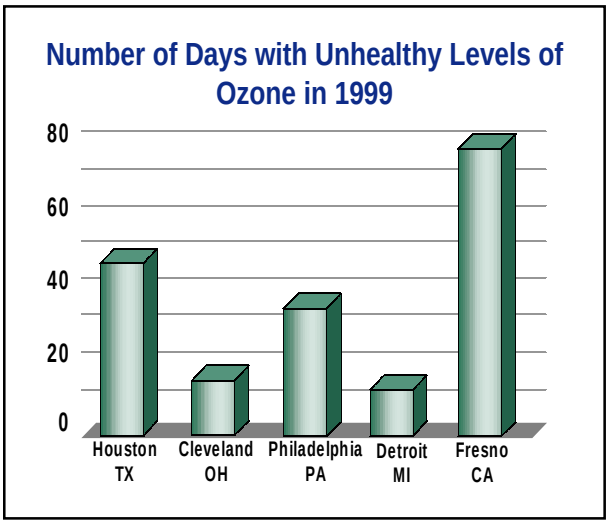
PM of all sizes affects respiratory function, with smaller particles (diameter < 2.5 μm) especially penetrating deep into the lungs. Premature mortality, aggravation of existing respiratory conditions (indicated by increased hospital admissions and emergency room visits, as well as lost school and work days), and changes in lung tissue and function are all linked to even low ambient PM concentrations.



Ozone

Nitrogen emissions can also indirectly affect respiratory function through the formation of ozone. While ozone is a naturally occurring and protective component of the upper atmosphere, its presence in the lower atmosphere poses health risks. Formed mostly as a product of combustion, NO_X is key to the chemical reaction that forms O_3. Both gases are important components of smog, are found predominantly in urban areas, and can travel long distances from their origins. In 1998 alone, an estimated 100 million people lived in *non-attainment areas* and therefore experienced exposure to ozone concentrations greater than the levels set by the NAAQS to protect public health.

Ozone has an especially strong impact on respiratory function when individuals are exercising, irritating even healthy lungs, decreasing the volume of air a person can take in with each breath, and causing fast, shallow breathing. Concentrations as low as 80 parts per billion (ppb) can cause damage when people are exposed for over eight hours at a time, as can levels of 120 ppb over even short periods of time. These conditions are common in urban areas across the country, especially in summer months when heat and humidity promote the production of ozone. In addition, ozone increases respiratory and pulmonary sensitivity and inflammation and overall susceptibility to respiratory disease.



Visibility Impact/ Material Damage

Along with SO_2 emissions, nitrogen emissions contribute to an increase in regional haze and a resulting decrease in visibility. The same gases and particles that pose risks to lung tissue as fine particles also contribute to regional haze and obstruct our view. Scientists estimate that the natural range of visibility, absent the effects of pollution, would be

Effects of Haze-Causing Emissions on Visibility

approximately 110 to 115 miles in the western U.S. and 60 to 80 miles in the East. Under current conditions, visibility in the West is between 30 and 90 miles and 15 to 30 miles in the East.

While haze can affect any region of the country, its impact is felt most significantly in certain areas, including such landmark sites as the Grand Canyon, Yellowstone, Mount Rainier, Shenandoah, Great Smokeys, and Everglades National Parks. EPA is working with other federal agencies and states to cut emissions of NO_x and other haze-causing pollutants in order to improve visibility at these and other sites. In May 2001, EPA announced a proposed rule to help states take steps to control haze-causing emissions from older power plants and industrial facilities. The proposal will affect facilities in 26 industrial categories listed in the Clean Air Act, including coal-fired utilities, industrial boilers, refineries, and iron and steel plants that were build between 1962 and 1977. Facilities would have to comply with the proposal no later than 2013.

Reducing atmospheric concentrations of nitrogen compounds will also lessen the harmful impacts of air pollution on buildings and other structures, especially those made of calcite-rich materials such as marble and limestone. When nitric, sulfurous, and sulfuric acids in polluted air react with the calcite in marble and limestone, the calcite dissolves. In exposed areas of buildings and statues, we see roughened surfaces, removal of material, and loss of carved details. Stone surface material may be lost all over or only in spots that are more exposed. Acid deposition affects stone monuments across the U.S., including the Capitol Building and other national monuments in Washington, D.C.

Effects of Air Pollution on Structures

Carvings at the base of columns (above) show that carved details and sharp edges remain on sheltered areas. On an exposed portion of the carving (right), the edges of the marble have rounded and the surface has roughened.

While not as obvious as the damage done to stone, a wide variety of other materials are damaged the byproducts of NO_x emissions. Ozone chemically attacks elastomers (natural rubber and certain synthetic polymers), textile fibers and dyes, and to a lesser extent, paints. For example, elastomers become brittle and crack, and dyes fade after exposure to ozone.

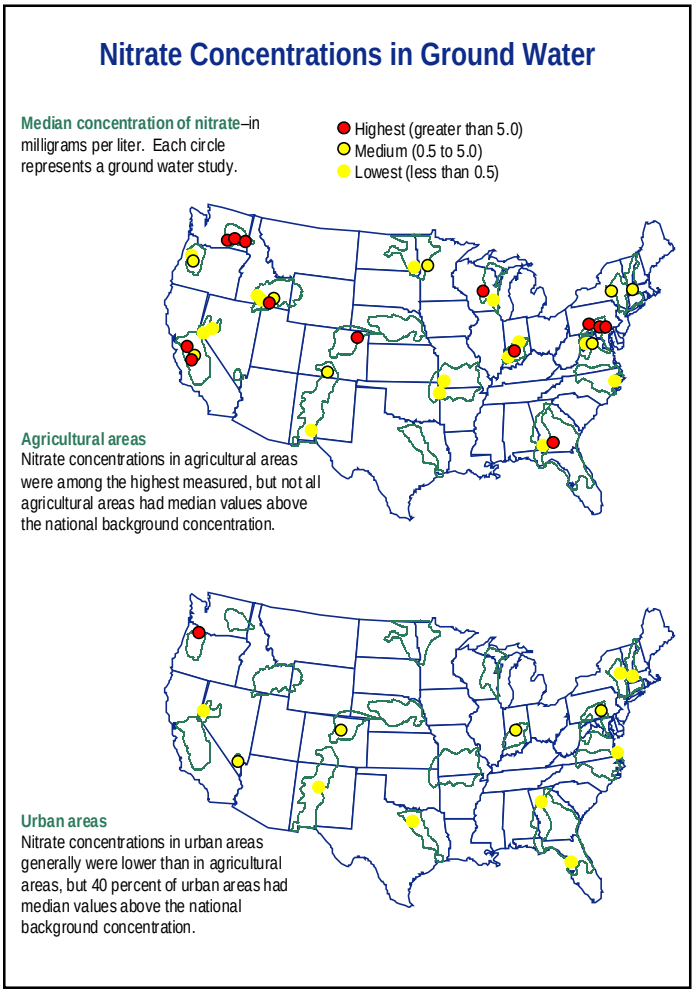
Aquatic Concentrations

Nitrate Concentrations in Drinking Water

As described above, respiration of airborne particles and compounds poses significant human health risks. However, other nitrogen pathways, such as drinking water supplies, also represent potential sources of risk. Nitrogen exists in ground- and surface waters in the form of nitrate ions (NO_3^-), whose levels are increasing in many parts of the country. Nitrate found in drinking water supplies comes from a variety of sources, primarily agricultural. While atmospheric deposition is not the principal source of nitrate in surface and ground water, increasing numbers of watersheds across the country are experiencing greater atmospheric N impacts, thus raising concern.

The most notable human health impact from nitrate contamination of water supplies is methemoglobinemia, or Blue Baby Syndrome. This most frequently affects infants under one year of age and can cause brain damage or death. A 1990 survey estimated that 4.5 million people a year were potentially exposed to nitrate levels above the EPA's Maximum Contaminant Level (MCL) of 10 mg/L. Nitrate contamination is not currently generating significant numbers of documented cases of Blue Baby Syndrome.

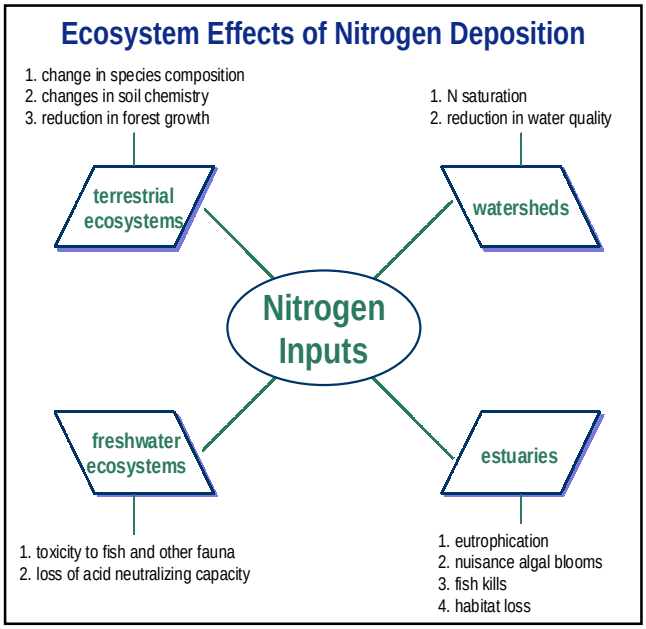
In addition, increased levels of nitrate in water supplies can increase the acidity of the water and make toxic metals such as mercury more soluble and therefore more available to fish, some of which might be consumed by humans.



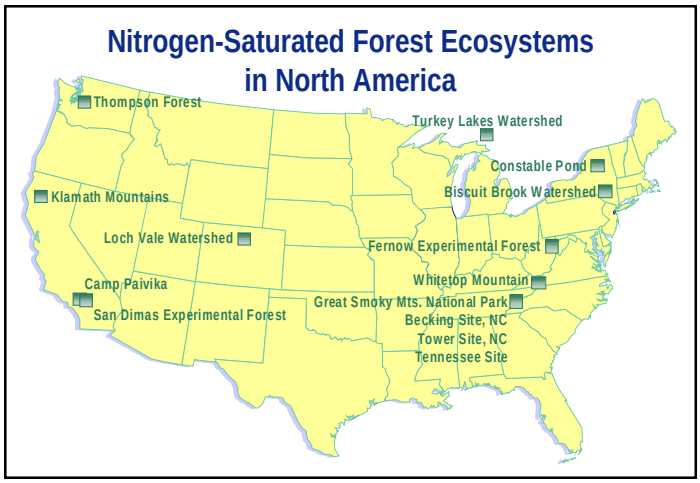
Regional Ecological Effects of Nitrogen Deposition

Once deposited to land and water systems, nitrogen compounds can have direct long-term effects on the chemistry of soil and surface waters such as lakes and streams, and can migrate to groundwater and estuarine environments. The movement of the pollutant over hundreds of miles in the atmosphere before being deposited, as well as its mobility through terrestrial and aquatic ecosystems, illustrates the potential for emissions to affect ecological systems far removed from their sources. These impacts are described in more detail below.

Terrestrial Systems

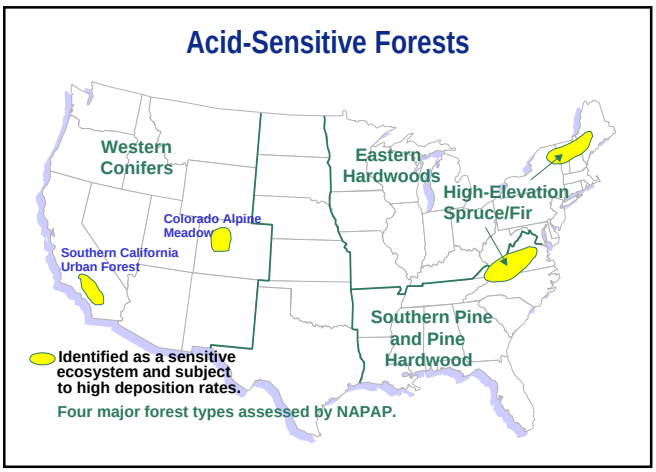


Deposition of nitrogen compounds at levels greater than the biological demand or need of the affected system can impact forest and other terrestrial systems in significant ways. Too much nitrogen can lead to a surplus of nutrients resulting in *over-fertilization*. This can impact species diversity by favoring some nitrogen-tolerant species over other species that are more sensitive to the nutrient. In some ecosystems, such as grasslands, nitrogen is the limiting factor for growth. In these systems, other nutrients are in sufficient supply, and so the amount of available nitrogen dictates what growth can take place. Plants living in these systems have adapted to low levels of nitrogen and are especially vulnerable to increased levels of nitrogen deposition. Their decline may lead to changes in the mix of plant species in an area, causing a decrease in species diversity. New plants may also move into nitrogen-rich ecosystems, further challenging native species. Animals that depend on specific plants for habitat and food may also be threatened by the changes resulting from nitrogen inputs.



Excess levels of nitrogen can change the natural cycle of plant uptake, transformation, and release, rob-

bing soils of their capacity to absorb nitrogen compounds. Known as *nitrogen (N) saturation*, this phenomenon involves the long-term removal of N limitations on biological activity, accompanied by a decrease in the ability of ecosystems to retain N inputs. As a result, nitrogen can migrate to surface waters or leach into groundwater, particularly in sensitive ecosystems with poorly buffered or thin soils (e.g., mountainous areas in the Colorado Front Range). As more terrestrial ecosystems reach the point of N saturation, nitrogen inputs reach groundwater and surface water in greater quantities, with effects that are discussed below.

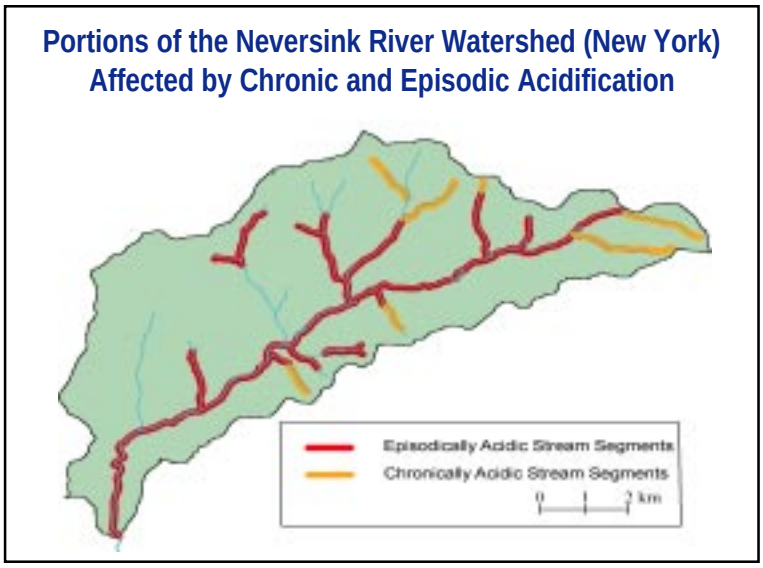


When NO_X and SO_2 emissions enter the atmosphere, they can be transformed into acids through complex chemical interactions. These acids return to the earth via precipitation or when plants come into direct contact with acidic cloud droplets or gases and airborne particles. Atmospheric deposition of nitrogen compounds and other pollutants modifies soil chemistry and concentrations of important soil nutrients. While a majority of acid deposition in the United States is due to SO_2 emissions, NO_X emissions are now recognized as an increasingly important source of the problem.

Extremely high levels of acid deposition, especially from cloud deposition, damage plant leaves and leach nutrients directly from foliage. Indirect effects of acid deposition are also responsible for damage to forest ecosystems, as acidic ions in the soil displace calcium and other nutrients from plant roots, inhibiting growth. Acid deposition can also mobilize toxic amounts of aluminum, increasing its availability for uptake by plants. Although overall acid deposition rates have declined during the past decades, ecosystems continue to show symptoms of *chronic acidification*. Moreover, evidence suggests that acid deposition due to nitrogen rather than sulfur emissions is not declining.

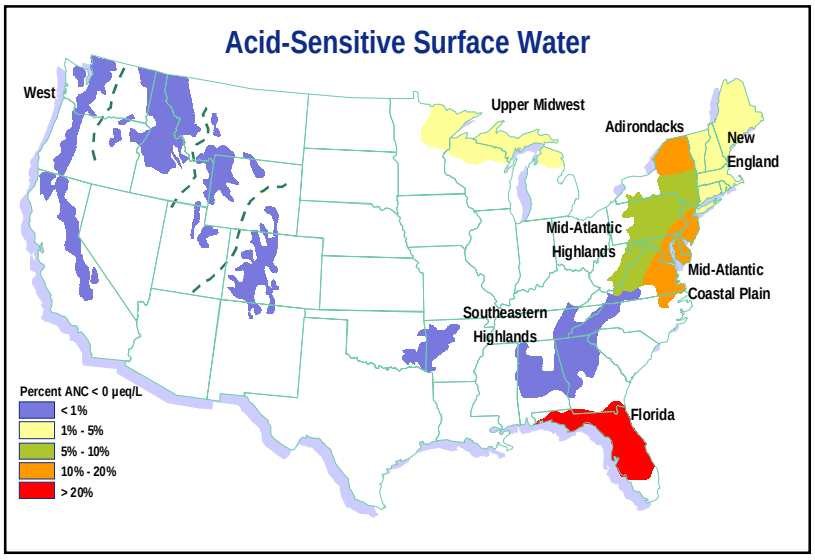
Freshwater Ecosystem Effects

Since growth in freshwater ecosystems is more often limited by phosphorous than by nitrogen, these systems do not generally suffer from over-fertilization due to nitrogen inputs. However, acidification due to SO_2 and NO_X emissions has caused extensive damage in some areas of the country. For example, 30 percent of Virginia trout streams are episodically acidic according to one study, and an

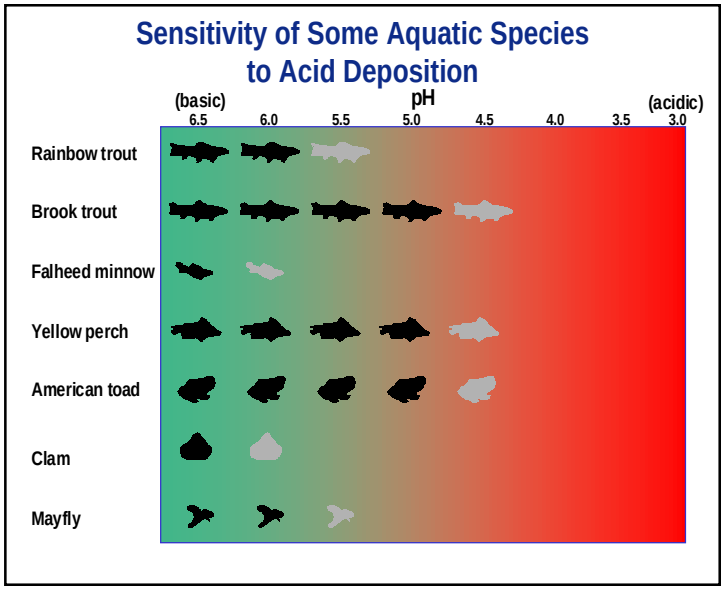


additional 20 percent are at significant risk of becoming acidic.

Acidification of surface waters results from both direct deposition of atmospheric acids onto bodies of water and from deposition of acids onto soils and plants, with subsequent leaching out of the *watershed*. The impact of acidification on various systems depends on their chemical properties. Some bodies of water are better able than others to neutralize additional inputs of acid, a characteristic known as *acid neutralizing capacity (ANC)*.



Even bodies of water with a high ANC are often unable to buffer seasonal spikes in acidic inputs. Many surface waters fall within a normal *pH* range during periods of normal flow but experience *episodic acidification*, or short periods of low ANC and high acidity, during storms or snowmelt. This temporary change in acidification is demonstrated by the situation in the Neversink, NY watershed. Levels of aluminum, which can be toxic to fish, often rise during acidification episodes. These events often fall at biologically sensitive times of the year such as early spring. Because many species are reproducing at this time of year, adults and young may both be unusually sensitive to changes in the water chemistry, increasing the impacts of nitrogen inputs. Addressing episodic acidification requires year-round rather than seasonal NO_X emissions reductions.

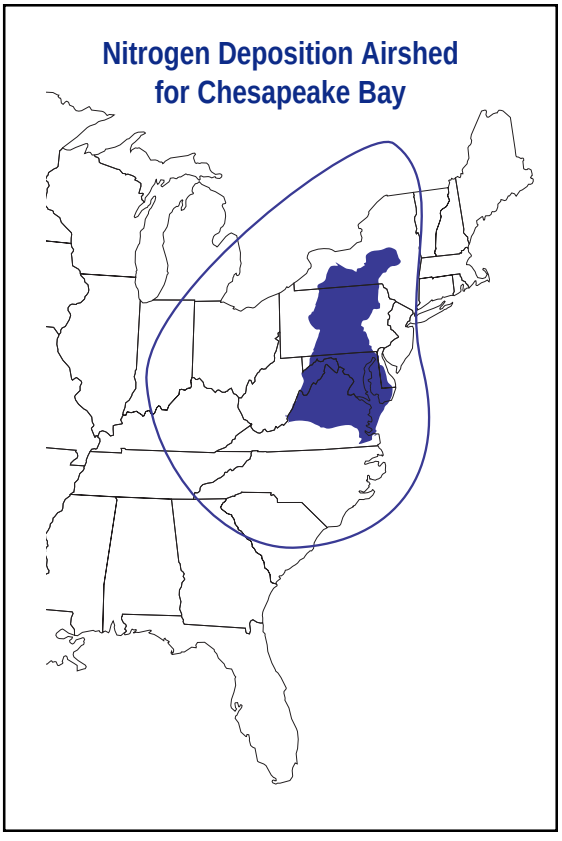


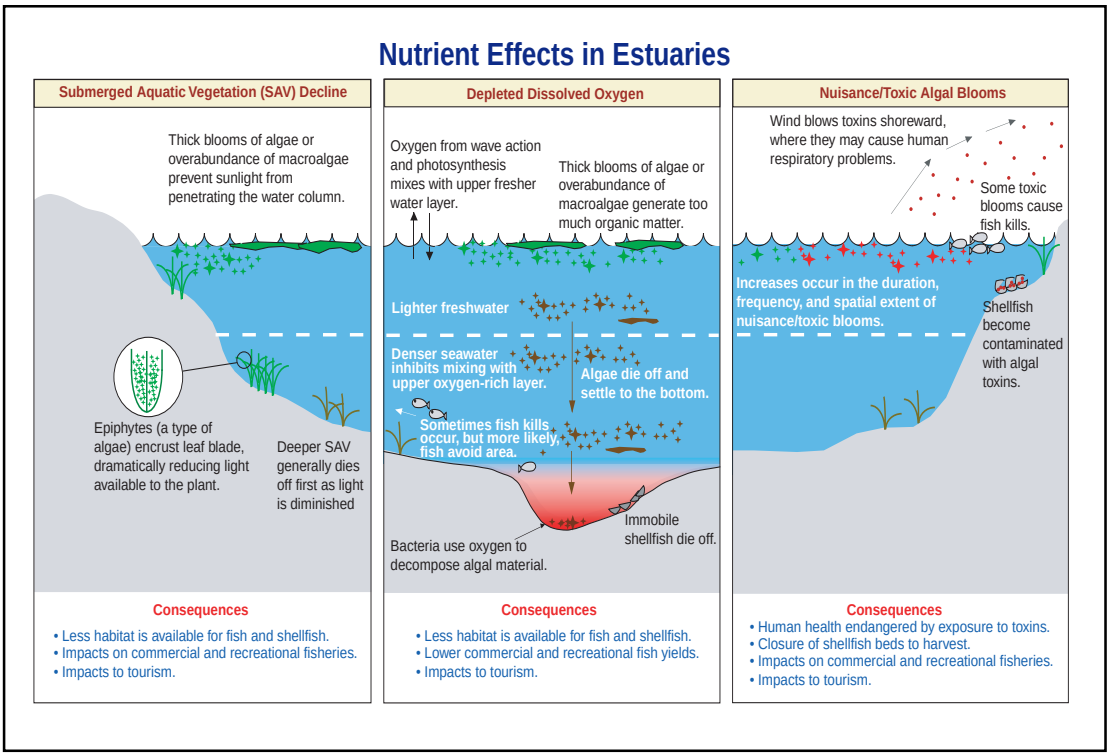
Acidification affects fauna throughout the food chain, resulting in significant direct and indirect damages to local fish populations. Even when fish are not immediately killed by increases in acidity, impacts on food sources may force specific species to migrate to less acidic areas. Acidification of surface waters leads to a decline in species diversity as sensitive species are replaced by species that are more acid-tolerant.

Coastal Ecosystem Effects

Nitrogen is a limiting nutrient for plants and animals in many coastal ecosystems. As a result, increases in nitrogen and other nutrients frequently increase the rate of supply of organic matter, particularly algae, to waterbodies such as estuaries. This phenomenon is known as *eutrophication*, and can lead to a loss of oxygen in the water, a condition referred to as *hypoxia*. When excessive quantities of algae grow in response to extra nutrients, they eventually die and fall to the bottom of the estuary, where they are decomposed by bacteria. Decomposition consumes oxygen and can deprive an estuary of oxygen needed for plants, fish, shellfish, and other organisms to live.

While nutrients reach estuaries from a variety of sources, atmospheric deposition is a key pathway as nitrogen is deposited both directly onto estuarine waters and onto waters and lands in the watersheds that flow into an estuary. Some of the nitrogen deposited on the watershed can eventually flush into an estuary; taken together, atmospherically deposited nitrogen from both direct and indirect sources can account for as much as 25 percent of all nitrogen inputs to a large estuary such as the Chesapeake Bay. The size of the watersheds and especially *airsheds* which contribute nitrogen to a given estuary are vast in comparison with the size of the actual water body. An airshed, like a watershed, is an area in which emissions contribute to the contamination of a water body. In contrast to watersheds, however, which define relatively clear boundaries for the flow of surface waters, there are no clear boundaries to the flow of chemicals in the atmosphere. The "boundaries" for an airshed do not mean that emissions from outside the airshed have no impact, nor that emissions from inside are all of equal impact. The absolute influence from an emissions source, in terms of likelihood of deposition on land or water, continuously diminishes as the distance from the source increases. Thus, an airshed can be de-



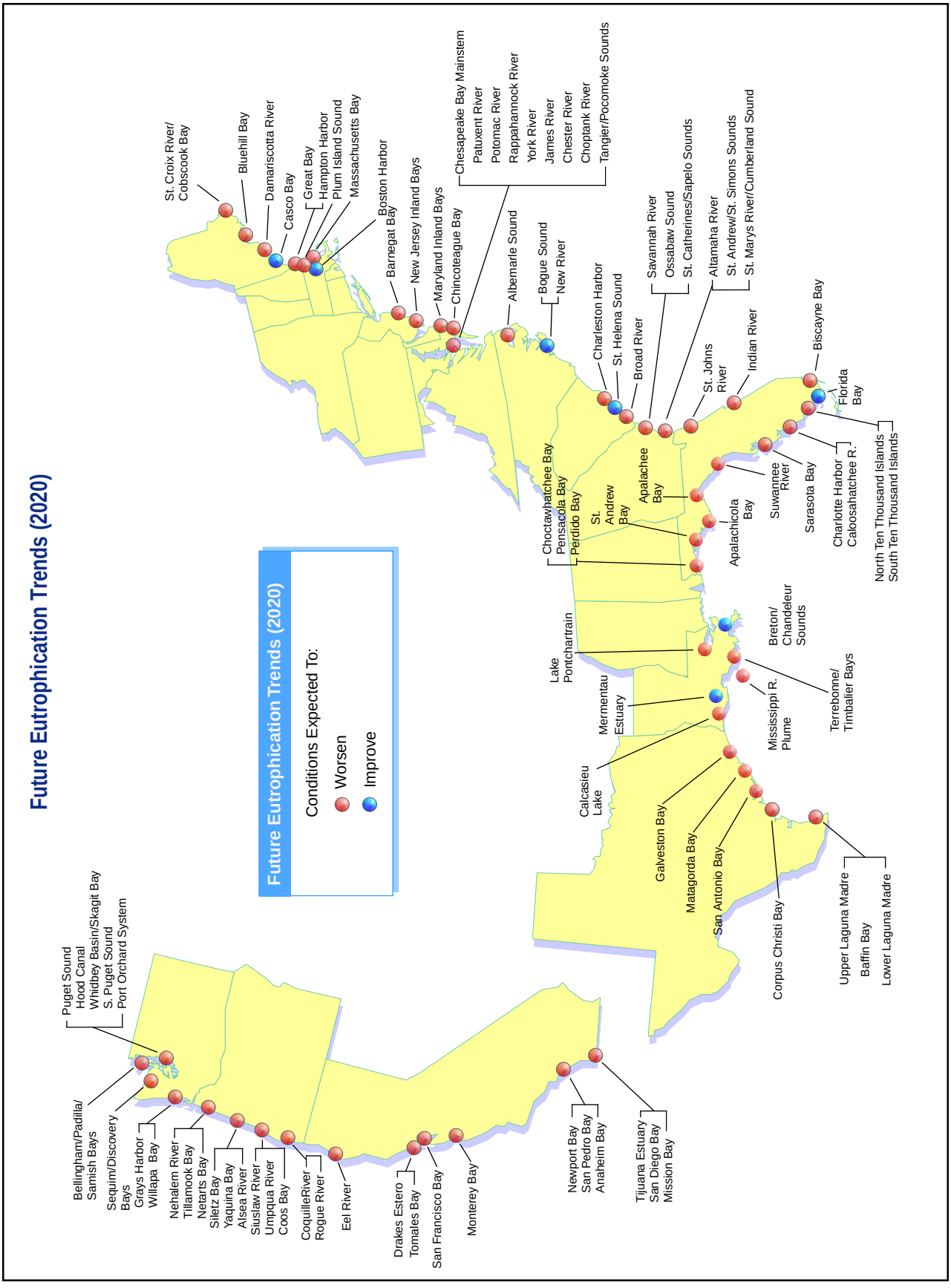


fined as the geographic area that encompasses emissions that are most important to the deposition across the watershed and account for the major percentage (usually around 75 percent) of that deposition.

The most commonly cited impacts of eutrophication are declines in commercial and recreational fisheries and shellfisheries, resulting largely from damage to sea grass and other habitats. These impacts are felt in the economy both directly due to the lost catches and indirectly through decreases in tourism in areas where fishing and shellfishing are impaired. In addition, increases in algal populations, referred to as algal blooms, can result in large floating mats of algae with impacts on swimming and boating. When this mass of algae begins to decompose, it often produces noxious smells with expected impacts on the recreational and aesthetic values of the waterways.

Increased quantities of nutrients may also be connected with an increase in the growth of toxic algal blooms. These blooms, often referred to as brown or red tides, can make water unsafe for swimming and can contaminate fish and shellfish harvested from the area. While links between nutrients and hazardous algal blooms continue to be researched and confirmed, incidence of the blooms is increasing and spreading to previously unaffected areas. As the population in coastal areas surrounding estuaries is expected to increase 13 percent in the next 20 years, additional strain will be added to already struggling estuarine ecosystems.

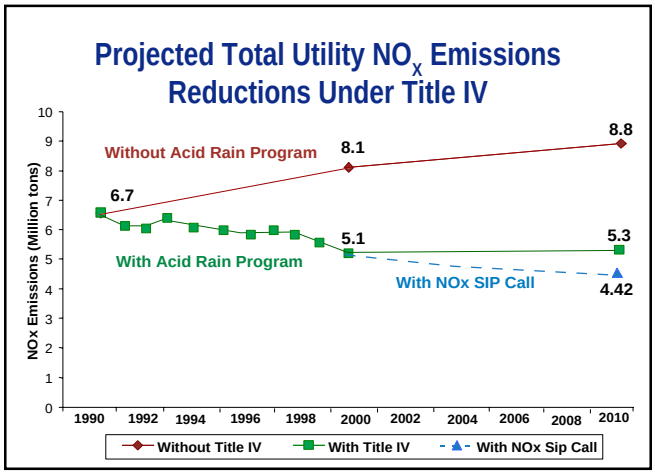
The National Oceanic and Atmospheric Administration (NOAA) recently released the results of an exhaustive seven year assessment of eutrophication in 138 estuaries. The assessment found that 65 percent of the major estuaries in the U.S. experience moderately to highly eutrophic conditions. These conditions are expected to deteriorate over the next 20 years in 86 of the estuaries studied, mostly located in the Pacific and Gulf of Mexico regions. It is important to note that many estuaries in the Pacific region currently exhibit only low to moderate eutrophic conditions, in contrast to many Atlantic and Gulf Coast estuaries. The projected deterioration is expected as a result of increasing coastal population density, combined with nitrogen inputs from agriculture, wastewater treatment, urban runoff, and atmospheric deposition. Taken together, these nitrogen inputs will place additional future strain


Future Eutrophication Trends (2020)
Future Eutrophication Trends (2020)
Conditions Expected To:
Worsen
Improve
St. Croix River/ Cobscook Bay
Bluehill Bay
Damariscotta River
Casco Bay
Great Bay
Hampton Harbor
Plum Island Sound
Massachusetts Bay
Boston Harbor
Barnegat Bay
New Jersey Inland Bays
Maryland Inland Bays
Chincoteague Bay
Chesapeake Bay Mainstem
Patuxent River
Potomac River
Rappahannock River
York River
James River
Chester River
Choptank River
Tangier/Pocomoke Sounds
Albemarle Sound
Bogue Sound
New River
Charleston Harbor
St. Helena Sound
Broad River
Savannah River
Ossabaw Sound
St. Catherines/Sapelo Sounds
Altamaha River
St. Andrew/St. Simons Sounds
St. Marys River/Cumberland Sound
St. Johns River
Indian River
Biscayne Bay
Florida Bay
Charlotte Harbor
Caloosahatchee R.
North Ten Thousand Islands
South Ten Thousand Islands
Sarasota Bay
Suwannee River
Apalachee Bay
St. Andrew Bay
Choctawhatchee Bay
Pensacola Bay
Perdido Bay
Apalachicola Bay
Lake Pontchartrain
Breton/ Chandeleur Sounds
Mermentau Estuary
Mississippi R. Plume
Terrebonne/ Timbalier Bays
Calcasieu Lake
Galveston Bay
Matagorda Bay
San Antonio Bay
Corpus Christi Bay
Upper Laguna Madre
Baffin Bay
Lower Laguna Madre
Puget Sound
Hood Canal
Whidbey Basin/Skagit Bay
S. Puget Sound
Port Orchard System
Bellingham/Padilla/ Samish Bays
Sequim/Discovery Bays
Grays Harbor
Willapa Bay
Nehalem River
Tillamook Bay
Netarts Bay
Siletz Bay
Yaquina Bay
Alsea River
Siuslaw River
Umpqua River
Coos Bay
CoquilleRiver
Rogue River
Eel River
Drakes Estero
Tomales Bay
San Francisco Bay
Monterey Bay
Newport Bay
San Pedro Bay
Anaheim Bay
Tijuana Estuary
San Diego Bay
Mission Bay

Efforts to Understand and Reduce NO_x Emissions

Federal and State Regulations

EPA and the states are using a number of regulatory programs and activities to address an important component of total nitrogen pollution - emissions of NO_x from both stationary and mobile sources. These efforts include programs to reduce NO_x emissions from new stationary sources; a program under Title IV of the Clean Air Act (CAA) to reduce NO_x from existing coal-fired power plants; regional approaches such as the Ozone Transport Commission's (OTC) trading program; the NO_x SIP Call; state petitions under Section 126 of the CAA; state programs implementing the NAAQS; and emissions standards for new mobile sources. Additionally, future efforts to meet the PM standards and address regional haze will result in reductions of NO_x emissions and ambient nitrate concentrations.



New Stationary Sources

New Source Performance Standards

New source performance standards (NSPS) require emission reductions in both attainment and non-attainment areas. Section 111 of the CAA requires EPA to identify "source categories" emitting criteria air pollutants (e.g., PM) or precursors of criteria pollutants (e.g., NO_x and VOCs) and to establish emissions limits for new, modified, and reconstructed stationary sources of emissions. To date, EPA has promulgated approximately 100 NSPS, of which approximately ten directly control NO_x emissions.

In September 1998, EPA finalized an NSPS for fossil fuel-fired utility and industrial boilers. These final revised NO_x emission limits will reduce the projected growth in NO_x emissions from new sources by approximately 42 percent from levels allowed under current standards.

New Source Review and RACT

Under the CAA, States must apply similar requirements to major stationary sources for NO_x emissions as are applied to major stationary sources of VOCs, because both are precursors to ozone. These provisions require (1) existing major stationary sources to apply reasonably available control technology (RACT) in certain ozone nonattainment areas and the OTC states, (2) new or modified

major stationary sources to offset increased emissions and to install controls representing the lowest achievable emission rate (LAER) in ozone nonattainment areas and the OTC states, and (3) new or modified major stationary sources to install the best available control technology (BACT) in ozone attainment areas.

Title IV

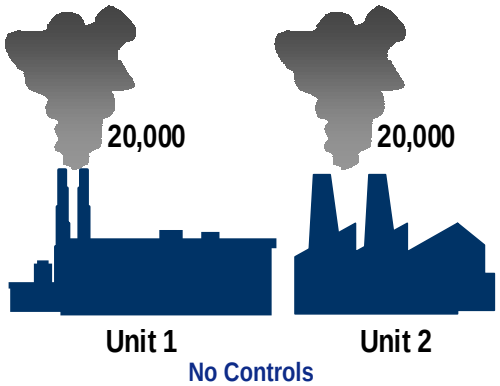
Title IV of the CAA specifies a two-part strategy to reduce NO_X emissions from coal-fired electric power plants. The first stage of the program, promulgated on April 13, 1995, reduced annual NO_X emissions in the United States by over 400,000 tons per year between 1996 and 1999 from two common types of boilers affected by Phase I of the Title IV SO_2 control program (Phase I). In the second stage of the Title IV Program, EPA established more stringent standards for those boiler types and established limitations for other types of coal-fired boilers. The Phase II NO_X rule will achieve an additional 1.7 million ton reduction of annual NO_X emissions (for a total of over two million tons), but this regulation does not include a cap on total NO_X emissions.

Under Title IV, EPA may only limit the quantity of NO_X released per unit of heat input and may not limit the total number of tons of NO_X released over the course of a year. Although emissions will be reduced significantly by this program, emissions are permitted to rise as more coal is used to generate more electricity. As a result, concern remains that without a cap on total emissions, continued increases in demand for electricity and transportation will offset some of the benefits of ongoing nitrogen reductions. Several states are considering year-round NO_X control programs with emissions caps, but until these programs encompass broader regions, emissions will continue to cross boundaries and cause damage.

OTC NO_X Budget Program

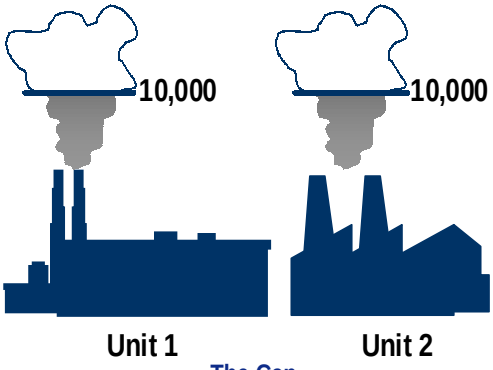
The OTC is comprised of the states of Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, New Jersey, Pennsylvania, Maryland, Delaware, the District of Columbia, and the northern counties of Virginia. In September 1994, the OTC members, with the exception of Virginia, adopted a memorandum of understanding (MOU) to achieve regional emission reductions of NO_X. In signing the MOU, states committed to develop and adopt regulations that would reduce region-wide NO_X emissions in 1999 and further reduce emissions in 2003. The OTC NO_X Budget Program represents the Northeast's principal mechanism to control NO_X emissions in order to make progress towards attainment of the ozone health standard.

The Emissions Cap and Trade Concept



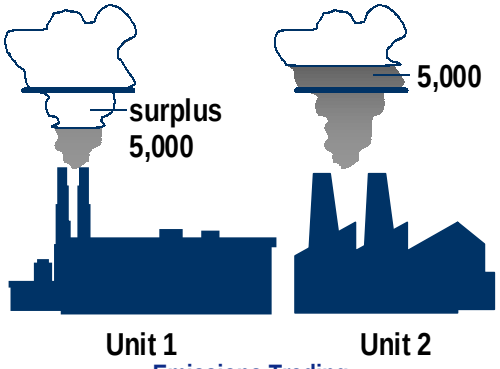
No Controls

With no controls in place, Unit 1 and Unit 2 each emit 20,000 tons a year.



The Cap

Each facility must choose an emission reduction strategy to meet its cap of 10,000 tons. Thus, each unit must achieve a 10,000 ton reduction from the 20,000 ton emissions level shown above.



Emissions Trading

Unit 1 can efficiently reduce 15,000 tons of emissions, but Unit 2 can only efficiently reduce 5,000 tons. Since Unit 1 can achieve greater reduction at less cost, it can hold on to the excess allowances or sell them to Unit 2. Through this exchange, the same amount of emissions reductions are achieved, but in the most efficient manner possible.

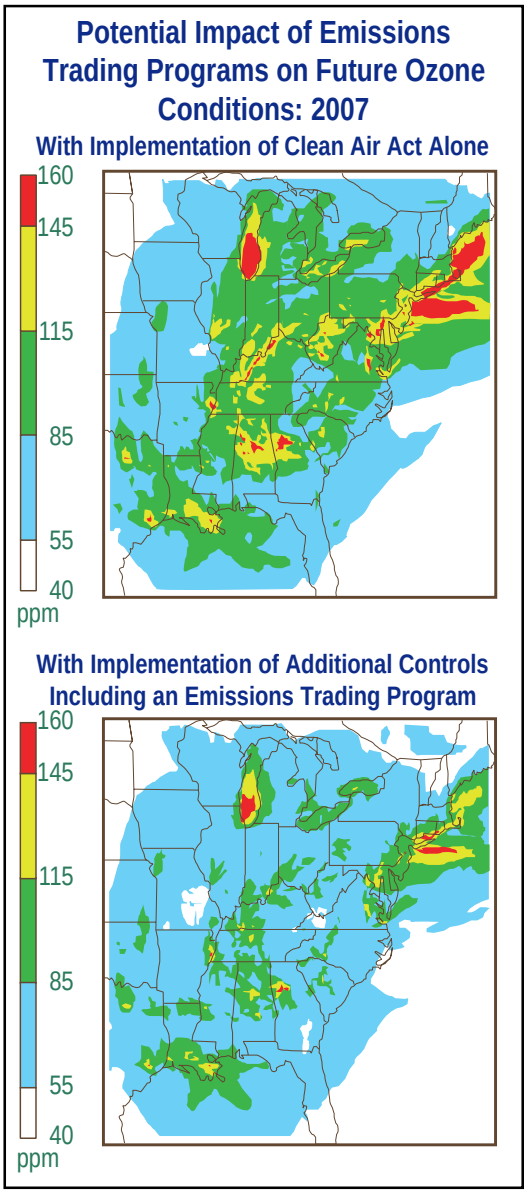
The OTC NO_X Budget Program involves an emissions cap (or budget) and an allowance trading system which harnesses free market forces to reduce pollution, similar to the U.S. EPA's Acid Rain Program for SO_2 emissions. Under this program, affected sources include all electric power plants with generators greater than 15 MWe and all industrial boilers with steam generating capacity greater than 250 mm Btu/hour. Sources are allocated allowances by their state governments. Each allowance permits a source to emit one ton of NO_X during the control period (May through September) for which it is allocated or during any later control period. For each ton of NO_X discharged in a given control period, one allowance is retired and can no longer be used.

In the summer of 1999, eight of the OTC States participated in the trading program. There were 912 affected sources which collectively emitted 174,843 tons of NO_X, 20 percent less than the maximum allowable level of emissions and more than 50 percent below their emissions in 1990.

NO_X SIP Call

In October 1998 EPA completed a rulemaking calling upon 22 eastern states and the District of Columbia to submit revised State Implementation Plans (SIPs) that provide for additional reductions in NO_X emissions. This rule is commonly called the NO_X SIP call. Although some of the affected states challenged EPA's authority to require these reductions, the DC Circuit Court of Appeals upheld the requirement for 19 states and parts of two others. Revised SIP submissions covering approximately 90 percent of the initial NO_X SIP Call emission reductions were due in October 2000, and should result in a reduction of almost 900,000 tons in NO_X emissions in 2007.

Among other provisions, the NO_X SIP rule assigns a cap, or "budget," on summertime NO_X emission to each of the affected states. States were required to submit plans to meet about 90 percent of these budgets by October 2000; they must have the mitigating technology in place by



2004; and they must have actual emissions at or below the set levels by 2007. EPA does not specify how a state must meet its requirements, but studies show that tightening NO_X controls at electric generating units and other large industrial sources would be an efficient first step.

With this in mind, EPA developed a model NO_X emissions trading program that states can choose to implement as part of their SIPs. Under the trading program, a state will assign each major source a number of allowances for the amount of NO_X it may emit (one allowance permits the release of one ton of NO_X). These allowances can be bought, sold, or saved for future use. If a facility emits more NO_X than the quantity for which it has allowances, then it must either purchase additional allowances or be considered out of compliance. Units that are out of compliance are subject to a deduction of three allowances for each ton they emit above the number of allowances they hold at the end of the year and may face additional penalties for noncompliance. This enhances economic efficiency, as those facilities that can most easily reduce emissions beyond allowable levels can sell extra allowances to those for which such changes would pose a greater financial burden. Regardless of how many allowances a facility holds, however, it may not emit at levels that would violate any other state or federal limits. This emissions trading program is similar to the trading program for SO_2 conducted by EPA's Acid Rain Program. In the first phase of the SO_2 cap and trade program, emissions dropped by 30 percent below the allowable level and costs are now estimated to be approximately 75% less than the amount first predicted by EPA.

Since warm summer temperatures foster the production of ozone, the summertime caps on NO_X can provide significant benefits, especially with respect to ozone levels. However, these reductions will have limited impact on winter and spring NO_X emissions and, therefore, do little to cut deposition loads that affect ecosystems during biologically sensitive times of the year.

Section 126 of CAA

In 1997, eight northeastern states petitioned EPA under Section 126 of the CAA, seeking to reduce the transport of NO_X from upwind states. In January 2000 EPA took final action on the

Recent Regulations Affecting NO_x Emissions

Regulation	Compliance Date	Affected Sources	Projected NO_x Emission Reductions (year by which reductions will be achieved)	Inclusion of Emission Cap in Regulation
New Stationary Sources New Source Performance Standard (NSPS) New Source Review (NSR)		Major new and reconstructed sources All major new and modified stationary sources apply NO_x Best Achievable Control Technology (BACT) or Lowest Achievable Emission Rate (LAER)	45,650 tons/year (2003)	No Cap
Title IV Acid Rain NO_x	Group 1 (Phase I): January 1, 1996 Group 1 (Phase II) and Group 2: January 1, 2000	Group 1: Coal-fired dry bottom wall-fired boilers, tangentially fired boilers Group 2: wet bottom boilers, cyclones, cell burner boilers, and vertically-fired boilers (nationwide)	2.06 million tons/yr (2000)	No Cap
Ozone Transport Commission Memorandum of Understanding	Phase I (NO_x RACT—see above): May 31, 1995 Phase II: May 1, 1999 Phase III: May 1, 2003	Fossil fuel-fired boilers and indirect heat exchangers with a maximum rated heat input capacity of 250 mmBtu/hour or more (applies to northeast Ozone Transport Region, including Washington, DC and the 11 northeastern States)	320,000 tons/yr (2003)	Cap
Section 126[1]	May 1, 2003		510,000 tons per ozone season (2007)	Cap
NO_x SIP Call[2]	State NO_x Budget Programs (and NO_x reductions) must be implemented by May 31, 2004; budgets to be achieved by 2007	19 States and the District of Columbia (DC)	880,000 tons per ozone season (2007)	Cap
Mobil Source Regulations	Tier I Tailpipe standards: 1996	Tier I Tailpipe standards: light duty vehicles and trucks	935,000 tons/yr (2010)	No Cap
	Tier II Gasoline Sulfur Program: 2004 for gasoline sulfur content nationwide; 2004-2009 for tighter NO_x standards for vehicles	Gasoline nationwide, and cars, light trucks, and SUVs up to 10,000 pounds gross weight sold outside California	4.454 million tons/yr (2030)	
	National Low Emission Vehicle (NLEV) Standards: 1999 in NE ozone transport region; 2001 nationwide	National Low Emission Vehicle (NLEV) Standards: light-duty vehicles and light light-duty trucks	199,100 tons/yr (2007)	
	Heavy-duty highway diesel standards: 2004	Heavy-duty highway diesel standards: heavy-duty highway diesel engines	1.1 million tons/yr (2020)	
	Heavy-duty non-road diesel standards: 1999-2006	Heavy-duty non-road diesel standards: heavy-duty diesel construction, agricultural, industrial engines	1.2 million tons/yr (2010)	
	Small spark-ignition engine standards, phase I: 1997 Small spark-ignition, non-handheld engine standards, phase II: 2001-2007	Small spark-ignition engine standards, small spark-fired engines Small spark-ignition, non-handheld engine standards	9,900 tons/yr (2020)	
	Locomotive engine standards: 2000	Locomotive engine standards: new and rebuilt locomotive engines	493,900 tons/yr (2010)	

[1] Reductions under the Section 126 action are required to begin on May 1, 2003. States may chose to regulate some or all of the same sources that EPA is regulating under the Section 126 action under the NOx SIP Call starting in 2004. For 2004 and beyond, therefore, emissions reductions from the SIP Call action and the Section 126 action should not be considered additive.

[2] As originally finalized, the NO_x SIP Call covered 22 States and the District of Columbia and required 1.1 million tons of NO_x reductions. Based on a March 3, 2000 DC Circuit Court Decision, the geographic scope of the SIP Call and the overall reductions required were slightly reduced. Some additional reductions could be required depending upon finalization of rules to address issues remanded to EPA.

Section 126 petitions requiring sources in 12 states and the District of Columbia to reduce their NO_X emissions during the summer beginning in 2003. In addition to sources in the OTC states, this action would affect large electric generating facilities and industrial boilers in Ohio, West Virginia, and Virginia, as well as portions of Michigan, Indiana, and Kentucky.

NAAQS

EPA sets limits for the ambient concentrations of certain pollutants using its authority under the CAA. These limits are designed to protect public health and welfare throughout the United States and are referred to as NAAQS. These standards apply to the criteria pollutants: Sulfur Dioxide, Nitrogen Dioxide, Ozone, Particulate Matter, Carbon Monoxide, and Lead. EPA and the states share authority for controlling emissions from stationary and mobile sources. EPA sets the NAAQS and then asks states to submit SIPs which consist of the rules and legislation that the state has passed in order to meet the standards. If a state fails to submit a plan that attains and maintains these standards, EPA is required to develop and implement a federal implementation plan (FIP).

While emissions of five of the six criteria air pollutants are down since 1970, emissions of NO_X have risen by 17 percent over this same time period. The rate of increase has slowed dramatically in recent years because of federal and state actions, and there was only a net increase of two percent over the last decade.

Mobile Source Emission Limits

Over the last three decades EPA has set increasingly stringent tailpipe standards for automobiles, trucks, and buses. The effect of those actions has been to reduce significantly the rate of NO_X emissions from new cars compared to those without controls.

In December 1999, EPA announced new limits for tailpipe emissions of NO_X. In the next 10 years, these "Tier II" standards will require a 77 percent reduction in emissions from cars and as much as a 95 percent drop in emissions from sport utility vehicles and light trucks. EPA projects that virtually the entire national fleet of cars will be replaced by these cleaner-burning Tier II vehicles by 2030, at which time the benefits of the resulting cleaner air will translate into the prevention of 4,300 premature deaths, 173,000 cases of respiratory illness, and 260,000 childhood asthma attacks each year. In addition to these improvements in emissions from gasoline-burning

cars, EPA has promulgated similarly tough standards for diesel trucks. With these standards finalized, EPA also plans to address non-road vehicles such as farm and construction equipment.

In addition to the regulation of NO_X under the Clean Air Act, the Clean Water Act and the Safe Drinking Water Act address releases of nitrogen to surface and groundwater. The 1998 Clean Water Action Plan requires EPA to conduct research and develop assessments of the scope and impact of nitrogen deposition on all waters. It also asks EPA to work with its partners to use both Clean Air Act and Clean Water Act authorities to reduce atmospheric deposition of nitrogen that harms aquatic ecosystems. Actions under these statutes include developing and submitting several Reports to Congress that outline the effects of nitrogen deposition and the effects of current or possible future control strategies; working with USDA to make sure atmospheric deposition issues are addressed in the Concentrated Animal Feeding Operations strategy; and supporting modeling, monitoring, and specific research projects related to atmospheric deposition of nitrogen and its effects.

Tracking Nitrogen for Accountability: Long Term Monitoring and Assessment

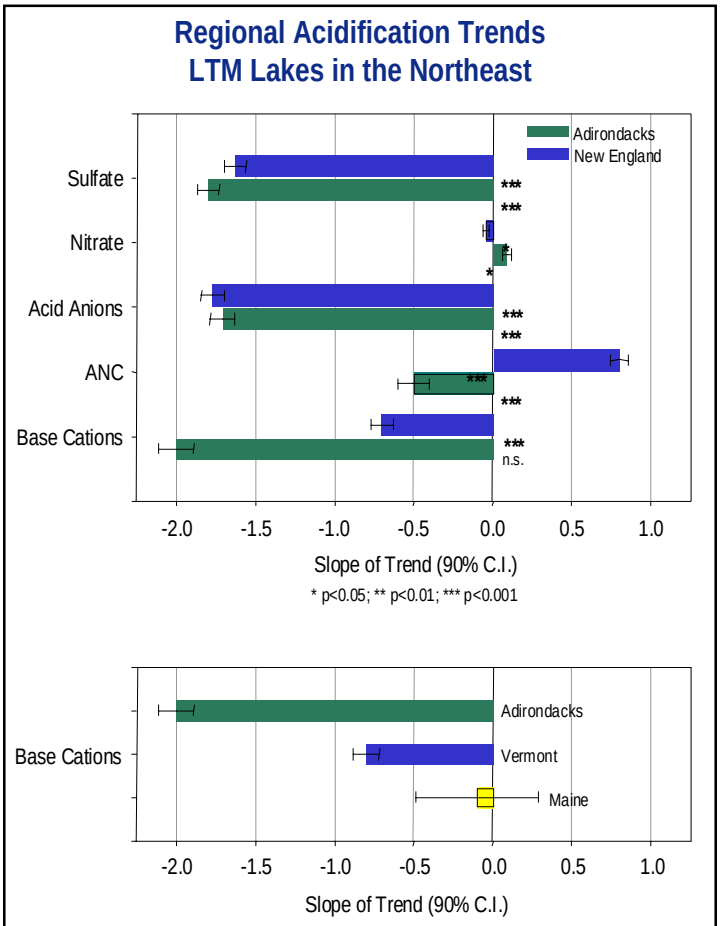
In order to evaluate the effectiveness of environmental policies and programs, a firm commitment to long-term monitoring programs is critical. These programs help in evaluating the status and trends of visibility, the health of ecosystems, and other important assessment endpoints. For example, monitoring data allow the Agency to evaluate the effectiveness of emission controls, explore dose-response relationships, and understand ecological processes. Effective assessment of environmental policies and programs requires a full suite of monitoring capabilities, including tracking stack emissions, analyzing atmospheric concentrations of pollutants, measuring wet and dry deposition on land and water surfaces, and evaluating the ultimate environmental impacts through surface water chemistry and biological monitoring.

Continuous emissions monitoring (CEM) is the ongoing measurement of pollutants emitted into the atmosphere in exhaust gases from combustion or industrial processes. While traditional emissions limitation programs have required facilities to meet specific emissions rates, compliance under the Acid Rain Program requires an accounting of each ton of emissions from each regulated unit. EPA has established requirements for the continuous monitoring of NO_X and SO_2 for units

regulated under the Acid Rain Program. Thus, CEM is instrumental in ensuring that the mandated reductions of NO_X and SO_2 under the Acid Rain Program are achieved.

Scientists have been monitoring precipitation chemistry for over 20 years. The National Atmospheric Deposition Program (NADP) is a cooperative effort established in the late 1970s between federal and state agencies, universities, electric utilities, and other industries to investigate geographical patterns and trends in precipitation chemistry in the U.S. Its network of monitoring sites known as the National Trends Network (NTN) monitors wet deposition through weekly collection of precipitation samples across the country. Similarly, the Clean Air Status and Trends Network (CASTNet) has monitored dry deposition of sulfur and nitrogen compounds since 1987. Measurement of dry deposition is complex, and so CASTNet measures ambient concentrations of contaminants along with meteorological conditions and then estimates the quantity deposited.

The Temporally Integrated Monitoring of Ecosystems and Long-Term Monitoring (TIME/LTM) networks serve a similar purpose for monitoring the impacts of acid deposition on surface waters. Concentrated in the Mid-Atlantic and Northeast, the TIME/LTM networks monitor both chronic and episodic acidification. The TIME network survey sites are sampled annually in order to determine changes in chronic acidification at a regional scale. Complementing these



Analysis of Northeast regional trends in surface water chemistry between 1982 and 1994 (Adirondack Mountains, New England) shows that sulphate concentrations decreased, with stronger downward trends evident in the 1990s than in the 1980s. Regional declines in nitrate concentrations were rare and smaller in magnitude. Recovery in alkalinity (as measured by Acid Neutralizing Capacity) was observed in the New England region in the 1990s, but not in the Adirondacks.

sites, the LTM network monitors lakes and streams that are highly sensitive to acidic inputs. These bodies of water are sampled eight to 16 times per year in order to track episodic acidification and its connection with chronic acidification. Over 200 lakes and streams have been sampled under this program for the past six to nine years, providing researchers with the first body of empirical data with which to understand the relationship between acid deposition and episodic and chronic acidification, as well as to characterize ecological responses to changes in deposition loadings.

Other monitoring networks administered by government agencies across the country also collect data on nitrogen deposition and acidification. The National Park Service's (NPS's) IMPROVE program monitors visibility and the contaminants that affect it; the National Oceanic and Atmospheric Administration's AIRMoN program supports both the NADP precipitation chemistry and dry deposition networks; and the interagency (EPA and NPS) PRIMENet conducts intensive, long-term, multimedia monitoring of air, water quality, soil, and sediment quality stressors. The hundreds of monitoring sites that make up all of these networks provide the data on which scientists base estimates of damage and regulators evaluate and base decisions on emissions limits.

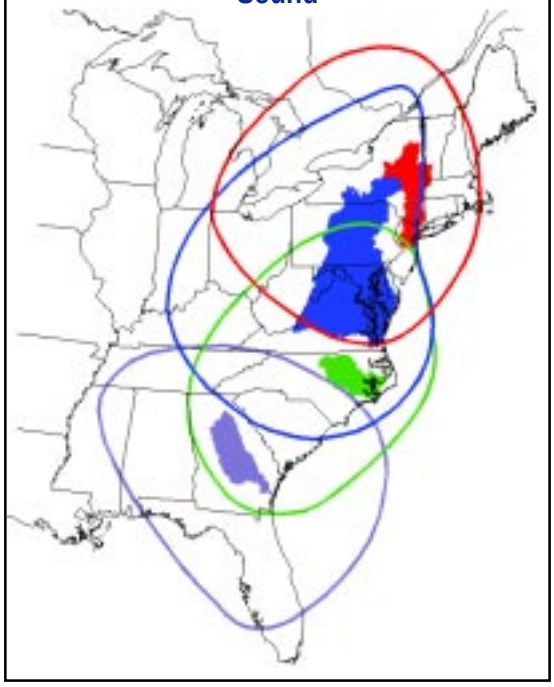
Monitoring over extended time periods and geographic areas is crucial to understand the effectiveness of environmental policy. Observation data for one month or one year may be misleading if taken out of the context of larger patterns of deposition, and conditions vary widely both within and across regions. Many of these monitoring sites have been functioning for over 20 years, providing a solid basis for judgement.

Conclusion

A Regional Problem

Nitrogen, and more specifically nitrogen oxides (NO_x), is indeed a complex and pervasive pollutant. Once emitted into the environment, it travels long distances through atmospheric, terrestrial, and aquatic systems. Accordingly, it causes direct and indirect impacts on human health and the environment, often hundreds or thousands of miles away from its source. Typically, public health and environmental problems become more regional in nature when it becomes apparent that multiple sources in multiple states contribute to the problem.

Principal Oxidized Nitrogen Airshed for Hudson/Raritan Bay, Chesapeake Bay, Pamlico Sound, and Altahama Sound



Nitrogen emissions can be linked to almost all the major environmental and health threats that the Clean Air Act addresses. Nitrogen combines with other compounds in the atmosphere to produce ozone and small particles, both of which cause serious respiratory problems, particularly affecting young children, asthmatics, and the elderly. Ozone can also reduce the resistance of important food crops to disease and pests. Particulate matter derived from nitrogen is a significant contributor to regional haze, affecting visibility especially in the western United States and in urban areas.

Excessive deposition of airborne nitrogen causes a range of environmental problems including the acidification of surface waters, groundwater, and soils; forest decline; loss of biodiversity; changes in the viability of flora and fauna; and eutrophication of coastal waters. While the most significant human health risks are currently posed by respiration of airborne particles and compounds, nitrogen exists in groundwater and surface waters in the form of nitrate ions, whose levels are increasing in many parts of the country.

What Still Needs to Be Done to Address the Problem?

EPA, along with other federal and state agencies, is engaged in a comprehensive monitoring and assessment program to better understand the effectiveness of current emission control programs

on the atmospheric concentrations of pollutants, deposition on land and water surfaces, and the ultimate environmental and human health impacts. For example, uncertainties remain regarding the possible links between nitrates and drinking water concerns.

A series of actions including the implementation of NAAQS affecting both mobile and stationary sources and NO_X reductions under the Acid Rain Program have achieved significant reductions in NO_X emissions. Nevertheless, additional reductions are needed to fully attain the ozone and fine particles NAAQS, address remaining environmental concerns (e.g., acid rain), and deal with emerging problems (e.g., coastal eutrophication).

While emissions of sulfur dioxide declined from 1990 through 1999, emissions of NO_X increased slightly. Although combustion processes are expected to become more efficient, without the implementation of an emissions cap, increases in the demand for electricity and vehicle travel will erode this progress. In addition, even though EPA has made significant progress in reducing summer NO_X emissions when human health impacts from ozone are greatest, more needs to be done on a year-round basis, especially to protect ecological systems. Many ecological impacts, including the damage to fish reproductive success, are at their greatest during the spring when snowmelt contributes to large increases in the acidification of lakes, rivers, and estuaries.

While much has been done, EPA remains committed to identifying, analyzing, and implementing cost-effective solutions to the complex regional consequences of nitrogen pollution.

Glossary

Acid deposition – complex chemical and atmospheric phenomenon that occurs when emissions of sulfur and nitrogen compounds and other substances are transformed by chemical processes in the atmosphere, often far from the original sources, and then deposited on earth in either wet or dry form. The wet forms, popularly called "acid rain," can fall to earth as rain, snow, or fog. The dry forms are acidic gases or particulates.

Acid neutralizing capacity (ANC) – measure of ability of water or soil to neutralize acidic inputs and resist changes in pH.

Airshed – area from which approximately 75 percent of the airborne emissions contributing to the contamination of a water body originate.

Atmospheric deposition – the process by which gases and particles in the atmosphere are deposited on terrestrial and aquatic surfaces.

Biological nitrogen fixation – process by which certain types of algae and bacteria pull nitrogen from the air, making it available for uptake by vegetation.

Chronic acidification – condition when an ecosystem exhibits symptoms of acidification over an extended period of time, rather than during temporary episodes.

Clean Air Act Amendments (CAAA) – federal legislation passed in 1990 enacting broad measures by which to improve air quality in the United States.

Cloud deposition – pathway in which acidic droplets in the atmosphere are deposited onto surfaces through direct contact.

Denitrification – process through which nitrate is transformed and re-emitted to the atmosphere as N_2O or N_2, forms of nitrogen which are not usable by plants and animals.

Dry deposition – process by which acidic compounds in the atmosphere are deposited directly onto surfaces in the absence of rain, snow, fog, or sleet.

Episodic acidification – temporary spikes in the acidity of a body of water due to surges in acidic inputs. These surges are most often associated with seasonal events such as snowmelt that can release quantities of stored nitrate ions.

Estuary – region of interaction between rivers and near-shore ocean waters, where tidal action and river flow mix fresh and salt water. Such areas include bays, mouths of rivers, and lagoons.

Eutrophication – An increase in the rate of supply of nutrients to a coastal ecosystem that leads to excessive algae growth, oxygen depletion, and resulting impacts on species and ecosystems.

Hypoxia – Condition in which the concentration of dissolved oxygen in water is less than the minimum required for most marine life to survive and reproduce.

Leaching – process by which soluble constituents are dissolved and filtered through the soil by a percolating fluid.

Methemoglobinemia – medical condition in which nitrates and nitrites in drinking water impair the ability of hemoglobin in the blood stream to transport oxygen (also known as Blue Baby Syndrome).

National Ambient Air Quality Standards (NAAQS) – standards established by EPA that apply to outdoor air throughout the country in order to protect public health.

Nitrate – compound containing one nitrogen atom and three oxygen atoms (NO_3^-) that can exist in the atmosphere or as a dissolved gas in water and which can have harmful effects on humans and animals. Nitrates in water can cause severe illness in infants and domestic animals.

Nitrogen – nonmetallic element that constitutes 78 percent of the air by volume, occurring as a colorless, odorless, almost inert diatomic gas, N_2, in various minerals and in all proteins.

Nitrogen cycle – series of processes in which nitrogen moves from the atmosphere to plants, soils, and waterbodies, and back to the atmosphere.

Nitrogen oxide (NO_x) – the result of photochemical reactions of nitric oxide in ambient air; major component of photochemical smog; product of combustion from transportation and stationary sources and a major contributor to the formation of ozone in the troposphere and to acid deposition.

Nitrogen saturation – a condition in forested ecosystems in which nitrogen impacts have led to long-term removal of N limitations on biotic activity, accompanied by a decrease in the capacity of an ecosystem to retain nitrogen.

Non-attainment area – area that does not meet one or more of the National Ambient Air Quality Standards for the criteria pollutants designated in the Clean Air Act.

Non-point source – diffuse pollution sources (i.e., without a single point of origin or not introduced into a receiving stream from a specific outlet). The pollutants are generally carried off the land by storm water. Common non-point sources are some agricultural, forestry, and mining practices; construction sites; dams; land disposal (e.g., landfills); saltwater intrusion; and urban runoff.

Over-fertilization – occurs when an ecosystem receives excess quantities of nitrogen or other fertilizing nutrients, and may result in a loss of species diversity.

Ozone (O_3) – gaseous allotrope of oxygen, formed naturally from diatomic oxygen by electric discharge or exposure to ultraviolet radiation. Its presence in the stratosphere protects the Earth from ultraviolet radiation, while its presence in the lower troposphere is damaging to plant, animal, and human health.

Particulate matter (PM) – fine liquid or solid particles such as dust, smoke, mist, fumes, or smog, found in air or emissions.

pH – an expression of the intensity of the basic or acid condition of a liquid; may range from 0 to 14, where 0 is the most acid and 7 is neutral. Natural waters usually have a pH between 6.5 and 8.5.

Smog – air contamination caused by chemical reactions of pollutants formed primarily by the action of sunlight on oxides of nitrogen and hydrocarbons.

Watershed – land area that drains into a stream; the watershed for a major river may encompass a number of smaller watersheds.

Wet deposition – commonly known as acid rain, although it can also take the form of snow, sleet, or hail; atmospheric deposition that occurs when precipitation carries gases and particles to the Earth's surface.

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