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Report to Congressional Requesters

March 2000

ACID RAIN

Emissions Trends and Effects in the Eastern United States

G A O

Accountability * Integrity * Reliability

GAO/RCED-00-47

Contents

Abbreviations

EPA	Environmental Protection Agency
NAPAP	National Acid Precipitation Assessment Program

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The Honorable Patrick J. Leahy
United States Senate

The Honorable John E. Sweeney
House of Representatives

Acid rain—which is largely the result of burning fossil fuels to generate electricity— can harm human health and damage forests, lakes, and streams. In the Clean Air Act Amendments of 1990, the Congress directed the Environmental Protection Agency (EPA) to decrease these adverse effects by reducing the emissions of the two major causes of acid rain—sulfur dioxide and nitrogen oxides—from electric utility power plants that burn coal and other fossil fuels. Sulfur dioxide and nitrogen oxide emissions return to earth (in a process called deposition) in various chemical compounds. Total sulfur deposition includes sulfates in precipitation (called wet sulfates), dry sulfate particulates, and dry sulfur gas. Similarly, total nitrogen deposition includes nitrates in precipitation (called wet nitrates), dry nitrate particulates, and dry nitrogen oxides.

The act places an annual limit on sulfur dioxide emissions from the largest electric utilities. It also allocates a number of emissions allowances—each representing the right to emit 1 ton of sulfur dioxide—to each power plant, based on historical usage and other factors, and permits the utilities (through a process known as allowance trading) to buy and sell these allowances and apply them against their annual emissions. The act also places an annual limit on the nitrogen oxide emission rate for individual utilities.

You asked us to analyze the trends from 1990 through 1998 in (1) sulfur dioxide and nitrogen oxides emitted into the air (emissions), at the national level; (2) deposition in the eastern United States and in three environmentally sensitive areas (the Adirondack Mountains, mid-Appalachian area, and southern Blue Ridge area); and (3) sulfates and nitrates in lakes in the Adirondack Mountains and the prospects for the lakes' recovery from the damage caused by acid rain. You also asked us to determine the extent to which utilities in 11 midwestern states used sulfur dioxide allowances originally assigned to utilities in their states, compared with allowances that originated in other states, particularly mid-Atlantic and northeastern states, during 1995 through 1998.[1]

Results in Brief

In the United States, total emissions of sulfur dioxide—one of two major causes of acid rain—declined 17 percent from 1990 through 1998, but total emissions of nitrogen oxides—the other major cause—changed little during the same time period. Meanwhile, sulfur dioxide emissions from electric utility power plants (the largest single source of such emissions) also declined 17 percent during this period, and nitrogen oxide emissions from electric utility power plants (the second largest source) declined by 8 percent.

In the eastern United States, total deposition of sulfur decreased 26 percent from 1989 through 1998, while total deposition of nitrogen decreased 2 percent, according to a preliminary analysis performed by an EPA contractor of data collected by EPA and other federal agencies. For the three environmentally sensitive areas, the trends were generally similar. For example, there was a 26-percent decrease—measured as the annual average for 1983-94 versus 1995-98—in wet sulfate deposition in the Adirondack Mountains.

In the Adirondack Mountains from 1992 through 1999, sulfates declined in 92 percent of a representative sample of lakes—selected by the Adirondack Lakes Survey Corporation, but nitrates increased in 48 percent of those lakes. The decrease in sulfates is consistent with decreases in sulfur emissions and deposition, but the increase in nitrates is inconsistent with the stable levels of nitrogen emissions and deposition. On the basis of our review of relevant scientific literature, it appears that the vegetation and land surrounding these lakes have lost some of their previous capacity to use nitrogen, which allowed more of the nitrogen to flow into the lakes and increase their acidity. Increases in these lakes' acidity raise questions about their prospects for recovering under the current program and being able to support fish and other wildlife.

The utilities in the 11 midwestern states relied on sulfur dioxide allowances that originated in those states for 11.2 million (81 percent) of the 13.9 million allowances they used from 1995 through 1998, according to EPA's

[1]The 11 midwestern states are Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Ohio, West Virginia, and Wisconsin.

data. Conversely, they used 2.7 million allowances that originated in other states, of which about 538,000 originated in six northeastern and mid-Atlantic states.

Background

The combustion of coal and other fossil fuels produces, as by-products, a wide variety of chemicals, including such gases as sulfur dioxide and nitrogen oxides.[2] These gases, which are emitted into the air and may be carried up to hundreds of miles by air currents, are transformed into acidic compounds, which are then returned to the earth. When the compounds are delivered by precipitation, such as rain and snow, the process is called wet deposition. When they are delivered as gases, aerosols, and particles, the process is called dry deposition. In addition, in high-elevation and coastal areas, they may be delivered through cloud or fog water, called cloud deposition.

While acid rain is the commonly used term, acid deposition is more accurate because it encompasses both wet deposition (through rain, snow, sleet, fog, and cloud water) and dry deposition (of gases, aerosols, and particles). Chemically, the deposition of sulfur dioxide and nitrogen oxides is acidic. Through various means, these emissions can cause harm to human health, various ecosystems, and material and cultural resources. (App. I describes the effects of acid rain on human health and selected ecosystems and the benefits of recovering from these effects.)

The Acid Rain Program, established by title IV of the 1990 amendments, required reductions of sulfur dioxide and nitrogen oxide emissions. Power plants can reduce their emissions by, for example, using coal that includes less sulfur or by installing equipment (called scrubbers) to trap sulfur dioxide before it is emitted into the air. The required reductions were expected to provide significant environmental benefits by reducing acid deposition levels and potentially reversing the impact of previous damage to various ecosystems and human health. To reduce these adverse environmental effects, title IV targeted the emissions from electric utilities, which were the source of 70 percent of sulfur dioxide emissions and 30 percent of nitrogen oxide emissions. By 2010, annual emissions of sulfur dioxide were to be reduced by 10 million tons (relative to the nation’s 1980 level of 25.9 million tons). Annual emissions of nitrogen oxides were to be

[2]These by-products include several compounds of nitrogen and oxygen, which we refer to generally as nitrogen oxides.

reduced by 2 million tons (relative to the nation's 1980 level of 24.8 million tons).

The program was implemented in two phases, with Phase I beginning in January 1995 and Phase II beginning in January 2000. Phase I mandated the participation of 263 of the largest electric utility power plant units in 21 states. Approximately 150 additional units—which would have been covered in Phase II—voluntarily participated in Phase I, bringing the total number of states to 25. Phase II affects an additional 2,000 units in all 48 contiguous states and the District of Columbia.

The program also established an allowance trading system that permits electric utilities to trade sulfur dioxide allowances and apply them against their annual emissions. The trading system allows the utilities more flexibility in planning how to achieve the required reductions in emissions and also enables them to minimize the costs of complying with these reductions.[3] The annual allowances for emissions were allocated to the affected utility units based on their historical fuel use, the emission rates specified in the law, and other factors. The utilities are required to own enough allowances at the end of each year to cover the emissions from the affected units. Allowances that are not used each year can be saved (or "banked") and used to cover emissions in future years.

The nitrogen oxide reductions are to be achieved by installing equipment to control these emissions. The legislation placed a limit on the annual emissions rate for individual power plants, measured in terms of pounds of emissions per amount of fuel burned. Although companies with several utility units may average their emissions rates, there is no limit on nitrogen oxide emissions and no general trading and banking system.

[3]For more information on allowance trading, see our report, *Air Pollution: Allowance Trading Offers an Opportunity to Reduce Emissions at Less Cost* (GAO/RCED-95-30, Dec. 16, 1994).

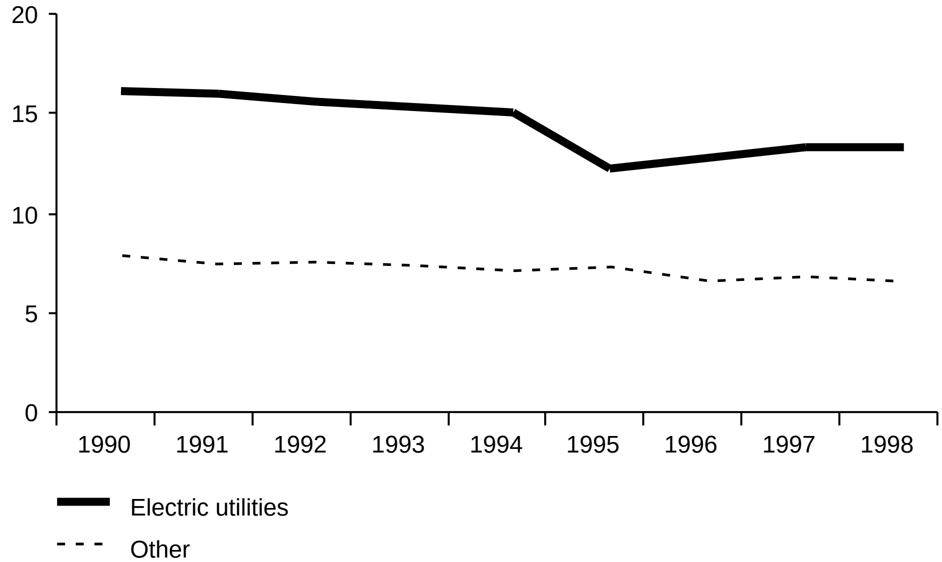
Sulfur Dioxide Emissions Declined Nationally, but Nitrogen Oxide Emissions Remained About the Same

Although emissions of sulfur dioxide declined from 1990 through 1998, emissions of nitrogen oxides changed little during that time period, according to EPA's data. Reduced emissions by power plants accounted for most of the decline of sulfur dioxide emissions. The decline in total sulfur dioxide emissions and stability in nitrogen oxide emissions during the 1990s continue the respective trends from 1975 through 1990.

Sulfur dioxide emissions from all sources declined from 23.7 million tons in 1990 to 19.6 million tons in 1998, according to EPA's data. This represents a decline of 17 percent. These emissions declined each year between 1990 and 1996, then increased each year from 1996 through 1998. Emissions from electric utilities declined from 15.9 million tons in 1990 to 13.2 million tons in 1998. This also represents a decline of 17 percent. (See fig. 1.) The largest year-to-year decline in electric utilities' emissions was from 14.9 million tons in 1994 to 12.1 million tons in 1995. From the 1995 level of 12.1 million tons, utility emissions rose to 13.2 million tons in 1998.[4]

[4]According to EPA officials, this increase is attributable primarily to higher emissions at power plants that were not covered by Phase I.

Figure 1: National Sulfur Dioxide Emissions, by Major Source, 1990-98

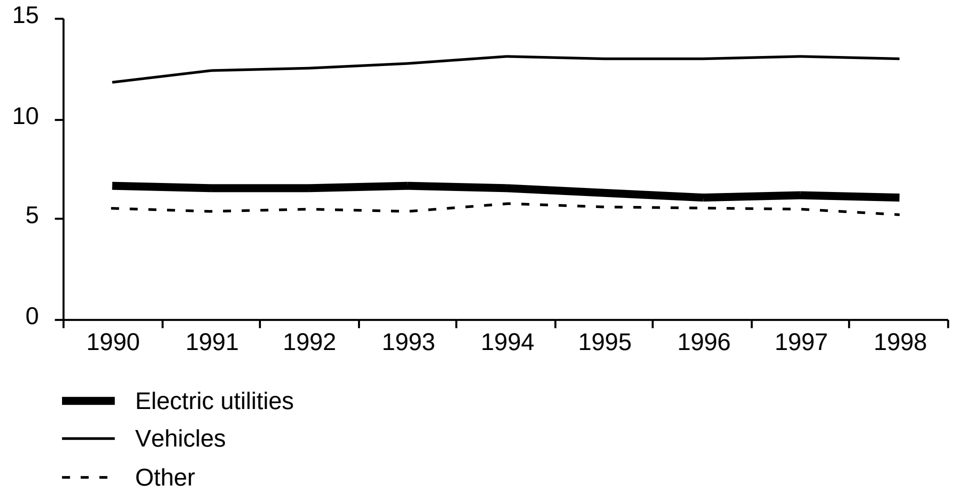


Source: EPA.

In 1998, electric utilities accounted for 67 percent of total sulfur dioxide emissions, according to EPA. Industrial fuel combustion and other sources accounted for the remaining 33 percent.

Nitrogen oxide emissions from all sources were 24.0 million tons in 1990 and 24.5 million tons in 1998, according to EPA's data. Although the total emissions level remained about the same, electric utilities' emissions declined from 6.7 million tons in 1990 to 6.1 million tons in 1998, representing an 8-percent decline. (See fig. 2.)

Figure 2: National Nitrogen Oxide Emissions, by Major Source, 1990-98



Source: EPA.

In 1998, on- and off-road vehicles and engines accounted for 53 percent of nitrogen oxide emissions. Electric utilities accounted for 25 percent. Industrial fuel combustion and other sources accounted for the remaining 22 percent.

In Eastern States, Sulfur Deposition Declined, but Nitrogen Deposition Changed Little, and in Environmentally Sensitive Areas, Trends Were Generally Similar

Total (wet plus dry) deposition of sulfur declined by an average of 26 percent in the eastern United States during 1989-98, according to a preliminary analysis prepared by an EPA contractor, while total (wet plus dry) deposition of nitrogen declined by 2 percent at the same locations.[5] Thus, the deposition trends followed trends in emissions. According to the Director, Institute of Ecosystem Studies, they are also consistent with the long-term (1963-99) trends observed at a site in New Hampshire.[6] Wet deposition of sulfates and nitrates—generally the largest component of sulfur and nitrogen deposition, respectively—recorded in three environmentally sensitive areas was generally consistent with the overall trends in wet deposition.

Two Monitoring Networks Collect Data on Deposition

Data on wet deposition come from the National Atmospheric Deposition Program's National Trends Network, which consists of over 200 monitors throughout the country. Data on dry deposition come from EPA's Clean Air Status and Trends Network, which consists of 74 monitors located primarily in eastern states. Data from both the wet and dry deposition monitoring networks are used to determine total deposition. For example, the data from the EPA contractor's preliminary analysis, which come from 34 wet and dry deposition monitoring stations, are thought—by EPA and its contractor—to be representative of overall deposition patterns in the eastern United States. In addition, in 1994, EPA initiated a monitoring project to measure cloud deposition at four locations, but, according to EPA officials, it discontinued the effort in 1999 because of budget constraints and the difficulty of interpreting the data. Although this monitoring effort and other short-term efforts have provided some data on cloud deposition, far less is known about cloud deposition than about wet and dry deposition, according to an EPA official.[7]

[5]The analysis was prepared by Environmental Science and Engineering, Inc. As of Feb. 1, 2000, EPA officials were reviewing the draft analysis.

[6]According to the director, Dr. Gene Likens, data from the Hubbard Brook Experimental Forest monitoring station in New Hampshire, which has the longest continuous record of precipitation chemistry measurement in North America, show that sulfur deposition has declined since 1963 and that nitrogen deposition, after increasing from 1963 through 1975, has been relatively stable since 1975.

[7]In some locations, cloud deposition is not only more acidic than other deposition, but it is equal to or greater than the amount of other deposition.

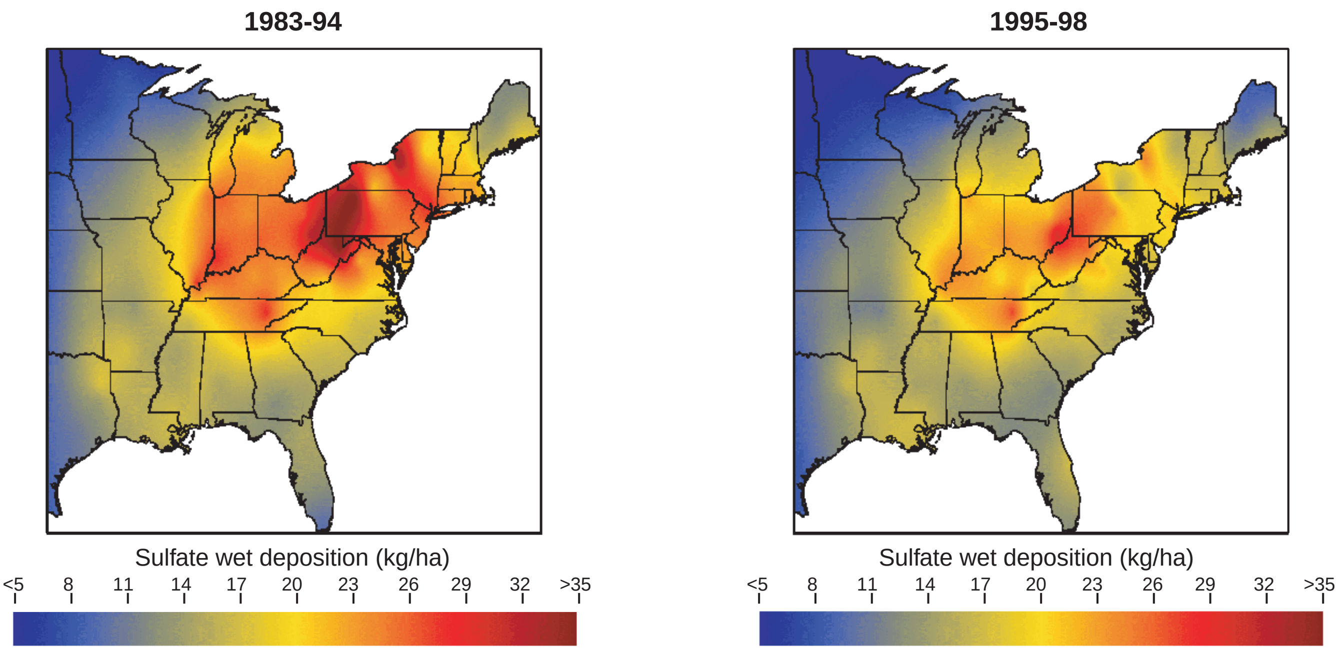
EPA officials provided the following information on measuring deposition. The actual amounts and relative proportions of wet and dry deposition for any given year depend on such factors as the amount and type of pollutants and precipitation. The relative proportions of wet and dry deposition vary widely by climatic region, with wet deposition constituting from 20 percent of the total in dry regions to 80 percent in rainy regions. To even out normal annual variations, deposition is often measured in terms of multiyear averages. Statistical tools have not yet been developed to discern the statistical significance of deposition trends for relatively short time periods. This limitation is particularly evident when changes in deposition are relatively small, and it may not be possible to distinguish how much of an apparent trend may be due to an actual change in deposition or to natural variations in climate. Most acid deposition trend analyses to date have focused on wet deposition, in part because it is the most easily and commonly measured form of deposition and because of concerns about the complexity of measuring dry and cloud deposition.

Wet Sulfate Deposition Decreased in the Eastern States and in Three Environmentally Sensitive Areas

Both wet and dry deposition of sulfur declined from 1989 through 1998 at the 34 monitoring stations, according to the preliminary analysis. Specifically, wet deposition declined by an average of 21 percent, while dry deposition declined by an average of 33 percent. Moreover, as shown in the maps in figure 3, there were widespread decreases in wet sulfate deposition in the eastern states between 1983-94 and 1995-98.[8]

[8]These maps are based on observations of wet deposition from 84 monitoring stations of the National Atmospheric Deposition Program that had sufficiently complete data. According to Dr. James Lynch, Professor of Forest Hydrology at Pennsylvania State University and Chairman of the National Atmospheric Deposition Program's Executive Committee, wet sulfur deposition in the eastern states during 1995-98 was from 10 to 25 percent lower than the 1983-94 trend.

Figure 3: Wet Sulfate Deposition in Eastern States, 1983-94 and 1995-98



Source: J.A. Lynch, V.C. Bowersox, and J.W. Grimm, "Changes in Sulfate Deposition in Eastern U.S.A. Following Enactment of Title IV of the Clean Air Act Amendments of 1990," *Atmospheric Environment*, in press 2000. Updated by the principal author to include data for 1998.

Moreover, in all three environmentally sensitive areas, wet sulfate deposition declined by 9 percent or more. As shown in table 1, the largest reduction—26 percent—was recorded in the Adirondacks; the next largest—23 percent—in the mid-Appalachian area;[9] and the smallest reduction—9 percent—in the southern Blue Ridge area.[10] According to the chairman of the deposition program's executive committee, these declines are primarily attributable to a significant decrease in sulfur dioxide emissions. For example, in the mid-Appalachian area, the sulfate concentration in rainfall decreased by 26 percent (due to lower emissions), while precipitation increased 4 percent.[11]

Table 1: Wet Sulfate Deposition in Three Environmentally Sensitive Areas

	Mean annual wet sulfate deposition (kilograms per hectare)		
Area	**1983-94**	**1995-98**	**Change from 1983-94 to 1995-98**
Adirondacks	25.5	18.9	-26%
Mid-Appalachian	27.8	21.4	-23%
Southern Blue Ridge	21.6	19.6	-9%

Source: Dr. James Lynch, Pennsylvania State University.

[9]The mid-Appalachian area includes Maryland, Pennsylvania, Virginia, West Virginia, and portions of northern New Jersey and southeastern New York.

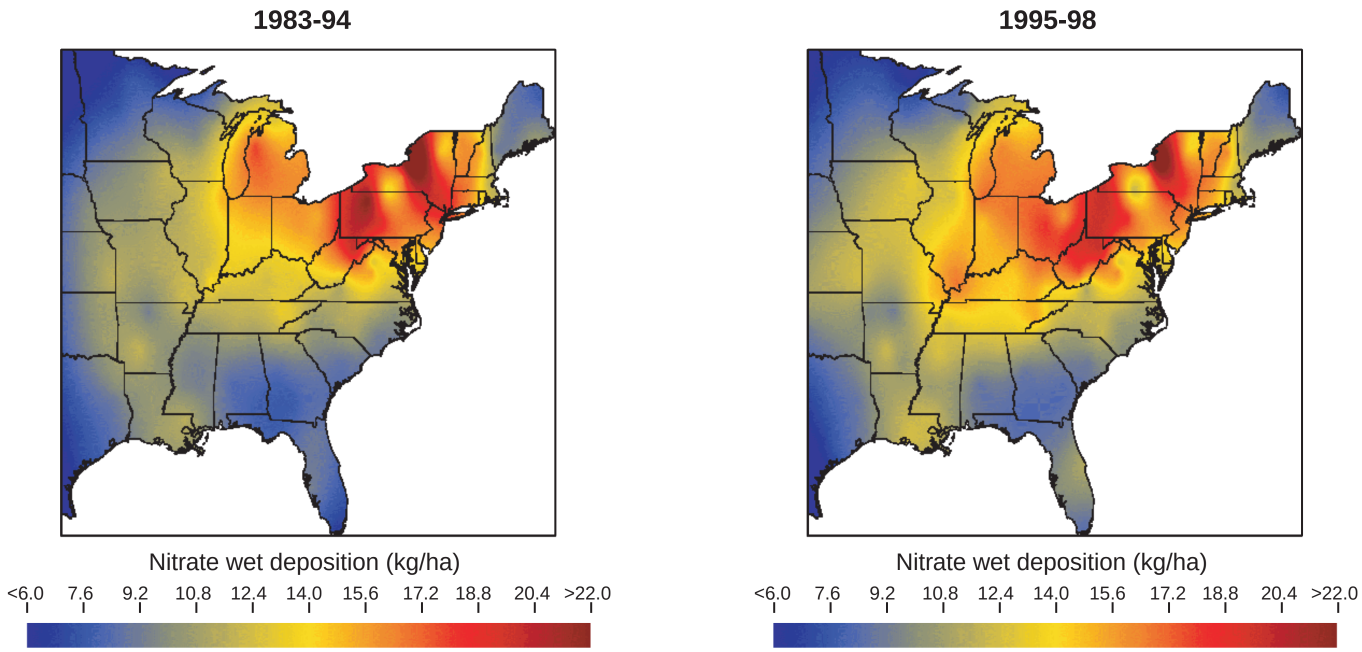
[10]The southern Blue Ridge area includes the southeast portion of Tennessee, the southwest portion of North Carolina, and the very northernmost portion of Georgia and South Carolina.

[11]According to the chairman of the deposition program's executive committee, the decreases in deposition in the Adirondack and mid-Appalachian areas appear to be due largely to decreases in emissions because precipitation was roughly the same in 1983-94 and 1995-98. However, for the southern Blue Ridge area, the relationship between emissions and deposition is less clear. This is because precipitation in the southern Blue Ridge area increased by 14.7 percent in 1995-98 relative to the 1983-94 level. The greater amount of precipitation in 1995-98 affected both wet deposition amounts and concentration levels. When such differences in precipitation occur, it is much more difficult to determine the relative importance of changes in emissions.

Wet Nitrate Deposition Generally Changed Little in the Eastern States and Three Environmentally Sensitive Areas

Total (wet plus dry) deposition of nitrogen changed little from 1989 through 1998 at the 34 monitoring stations, according to the preliminary analysis. Specifically, wet deposition decreased by an average of 7 percent, while dry deposition increased by an average of 9 percent. The divergence in trends for wet and dry deposition is believed to be due to natural variability in weather conditions and the geographic patterns of emissions during that time. The maps in figure 4 illustrate that there was little change in wet nitrate deposition in the eastern states between 1983-94 and 1995-98.

Figure 4: Wet Nitrate Deposition in Eastern States, 1983-94 and 1995-98



Source: J.A. Lynch, V.C. Bowersox, and J.W. Grimm, "Changes in Sulfate Deposition in Eastern U.S.A. Following Enactment of Title IV of the Clean Air Act Amendments of 1990," *Atmospheric Environment*, in press 2000. Updated by the principal author to include data for 1998.

The trends in wet deposition also differed somewhat among the three environmentally sensitive areas. As shown in table 2, there were declines in the Adirondacks (5 percent) and the mid-Appalachian area (4 percent), but there was an 11-percent increase in the southern Blue Ridge area. According to the chairman of the executive committee, these trends reflect different emissions and precipitation patterns in the three areas. For example, in the Adirondacks, the nitrate concentration in rainfall decreased by 6 percent (due to lower emissions) and precipitation increased by 2 percent, whereas in the southern Blue Ridge, the nitrate concentration decreased by 3 percent and precipitation increased by 14.7 percent.[12]

Table 2: Wet Nitrate Deposition in Three Environmentally Sensitive Areas

	Mean annual wet nitrate deposition (kilograms per hectare)		
Area	**1983-94**	**1995-98**	**Change from 1983-94 to 1995-98**
Adirondacks	19.7	18.7	-5%
Mid-Appalachian	17.4	16.7	-4%
Southern Blue Ridge	11.3	12.6	+11%

Source: Dr. James Lynch, Pennsylvania State University.

Increasing Nitrate Levels in Many Adirondack Lakes Raise Questions About Prospects for the Lakes' Recovery

In the Adirondack Mountains, sulfates in a representative sample of lakes declined in most cases between 1992 and 1999, which is consistent with the decrease in sulfur dioxide emissions on a national level and sulfate deposition in the eastern states. However, nitrates in almost half of these lakes increased during the same time period; this is not consistent with the essentially unchanged levels of nitrogen oxide emissions and nitrate deposition. On the basis of our review of the scientific literature, it appears that the increases in nitrates reflect a reduction in the capacity of the vegetation and lands surrounding these lakes to use nitrogen. Thus, more

[12]According to the chairman of the executive committee, the increase in precipitation, rather than a decrease in emissions, is likely the reason for the decrease in nitrate concentrations in this area.

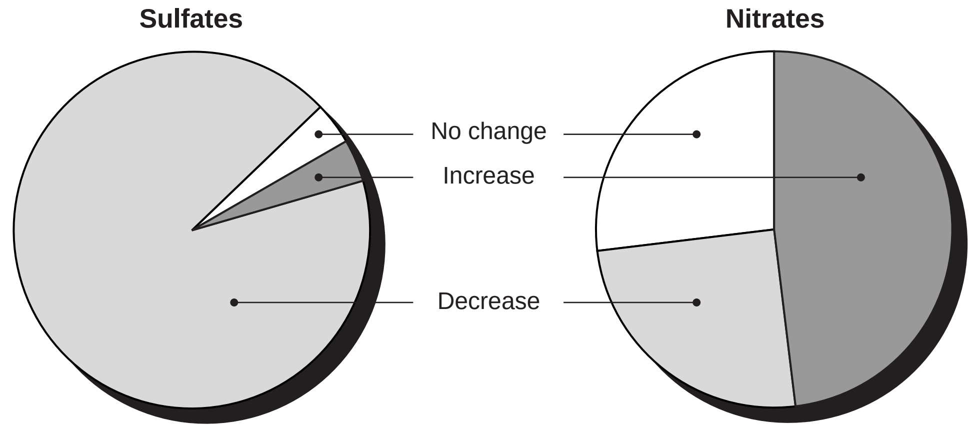
of the nitrates flow into the lakes and increase their acidity. Because of the long time periods that may be needed to reverse these factors, the prospects for recovery of the acidified Adirondack lakes are uncertain.

Sulfate Levels in Lakes Generally Decreased, but Nitrate Levels Often Increased

From 1992 through 1999, the amount of sulfates measured in sampled lakes in the Adirondack Mountains decreased in most cases, according to data collected by the Adirondack Lakes Survey Corporation.[13] Specifically, the amount of sulfates decreased in 48 of the 52 lakes (92 percent) regularly monitored by the corporation; the amount of sulfates was unchanged in 2 lakes and increased in the final 2 lakes, as shown in figure 5. (These lakes were selected to represent the characteristics, such as soil thickness and source of water, of lakes found in the area.) This is consistent with the declines in sulfur dioxide emissions and sulfate deposition. In contrast, during the same time period, the amount of nitrates measured in these lakes increased in many cases. Specifically, the amount of nitrates increased in 25 of the 52 lakes (48 percent), decreased in 13 lakes, and was unchanged in the remaining 14 lakes. This is not consistent with the essentially unchanged levels of nitrogen oxide emissions and nitrate deposition.

[13]This nonprofit corporation was formed in 1983 to gather information on the chemical condition and biological status of these lakes.

Figure 5: Changes in Sulfate and Nitrate Concentrations in 52 Adirondack Lakes, 1992-99



Source: Adirondack Lakes Survey Corporation.

Natural Processes Are Diverting Less Nitrates

According to the relevant scientific literature, the extent to which wet and dry sulfates and nitrates end up in lakes and streams depends on the amount of these acids that is diverted by natural processes. Most importantly, growing vegetation uses nitrogen as a nutrient. This capacity varies by season and by the age of the vegetation because vegetation requires nitrogen primarily during the growing season, and young, growing forests generally use more than older forests. In addition, the soils surrounding the Adirondack lakes have apparently lost some of their capacity to neutralize acids. Historically, years of acid deposition have depleted the soils' base elements (such as calcium), which provide the capacity to neutralize acids.

In the 1980s, when the Clean Air Act Amendments were being developed, it was believed that nitrogen would be a less important source of acidification than sulfur. As we noted in a 1984 report, trees and other vegetation use much of the nitrogen and, thus, prevent it from passing over or through the soil to streams and then to lakes.[14] However, that absorptive capacity has limits. In a 1995 study, EPA noted that this capacity could eventually become overloaded—a situation referred to as "nitrogen saturation."[15] As the vegetation on the surrounding land became saturated, more and more of the deposited nitrates would pass through to, and affect, the waters.

Seasonal patterns in nature compound the dangers posed by nitrogen saturation. This is because both the first melting of snow each year and the spawning of fish and other aquatic organisms occur in the spring. The water from the first melting is always the most concentrated in the acidic and other substances deposited in the snow that accumulated over the winter months. (The proportion of nitrogen in these substances tends to be high because, as noted above, nitrogen is generally not used by vegetation during the winter.) This highly acidic water often passes into lakes at about the same time as fish and other aquatic species lay their eggs or hatch their offspring, and these eggs and offspring are more vulnerable to the acidity than are the adults.

Prospects for Recovery of Adirondack Lakes Are Uncertain

Recovery of acidified lakes is expected to take a number of years even where nitrogen saturation is not a problem, according to the National Acid Precipitation Assessment Program (NAPAP).[16] According to various analyses, lakes in the Adirondack Mountains are taking longer to recover than lakes located elsewhere and are likely to recover less or not recover, without further reductions of acid deposition.

[14] *An Analysis of Issues Concerning Acid Rain* (GAO/RCED-85-13, Dec. 11, 1984).

[15] *Acid Deposition Standard Feasibility Study: Report to Congress*, EPA 430-R-95-001a, Oct. 1995.

[16] The program was established by the Congress in 1980 to study the processes and effects of acid precipitation.

In 1998, NAPAP estimated the time periods that would likely be needed for various ecosystems to respond to decreases in emissions.[17] Some of these time periods are shown in table 3.

Table 3: Time Periods Needed for Recovery of Selected Ecosystems

Ecosystem	Time period for recovery
Acute human health effects	Hours to weeks
Episodic effects on aquatic resources	Days to months
Chronic effects on aquatic resources	Years to decades
Soil nutrient reserves	Decades to centuries

Source: NAPAP.

In general, the recovery of lakes and streams may depend in part on the recovery of the surrounding soils. For example, U.S. Geological Survey researchers examining a set of streams across the eastern states found that, although the sulfates measured in these streams had declined over recent years, the streams' ability to counteract acidity (called acid neutralizing capacity) had not increased.[18] They concluded that the neutralizing capacity would not increase until the replenishment of base substances in the soil (called cations), provided largely by the weathering of the underlying rock, was greater than the rate of acid deposition. Thus, the lakes' recovery—if it is limited by the time required to weather the underlying rock—could take decades or even centuries.

Because of two factors, acidified Adirondack lakes may recover more slowly than other lakes. First, because many of the Adirondack watersheds have been exposed to acid deposition for long periods of time, their soils have been relatively depleted of substances that can neutralize acids. Second, the soils in the most acidified types of Adirondack watersheds are relatively thin (i.e., they offer little chance for contact between the soil and precipitation) and, thus, can offer less material to neutralize the acidic substances in precipitation. For both of these reasons, less acidic material

[17]See *NAPAP Biennial Report to Congress: An Integrated Assessment*, May 1998.

[18]David W. Clow and M. Alisa Mast, "Long-term Trends in Stream Water and Precipitation Chemistry at Five Headwater Basins in the Northeastern United States," *Water Resources Research*, Vol. 35, No. 2, pp. 541-54, Feb. 1999.

will be neutralized in the soil and more will flow into the waters. This analysis is supported by a 1998 study and by 1995 projections.

A peer-reviewed 1998 study analyzed lake acidity for 1982-94 for the Adirondacks and New England.[19] It found that the sulfate concentrations in all of those lakes generally declined. However, it also found that, while the New England lakes' acid neutralizing capacity improved significantly, the Adirondack lakes' capacity either showed no improvement or further declined. According to the study's authors, this difference is due to higher historic rates of acid deposition in the Adirondacks than in New England.

This finding is reinforced by the 1995 EPA study that projected how long it might take lakes and streams in three eastern areas to become acidified (to lose their acid neutralizing capacity).[20] The study prepared a series of scenarios on the number of years for these lakes and streams to become acidic, depending on the relative vulnerability of the different waters and the recuperative powers of their watersheds. For example, even with the reductions mandated by the 1990 amendments and assuming 50 years before nitrogen saturation developed, it estimated that 43 percent of the Adirondack lakes may become acidified by 2040.[21] This is more than twice the proportion (19 percent) observed to be acidic in 1984. It is also a far higher proportion, given the same assumptions, than for the mid-Appalachian (9 percent) and southern Blue Ridge (4 percent) areas. (See table 4.) On the other hand, also assuming 50 years before nitrogen saturation developed, but without the 1990 amendments, it estimated that 50 percent of the Adirondack lakes would be acidified by 2040.

[19] J. Stoddard et al., "A Regional Analysis of Lake Acidification Trends for the Northeastern U.S., 1982-1994," *Environmental Monitoring and Assessment*, Vol. 51, pp. 399-413, 1998. The study was based on data collected through EPA's Long Term Monitoring Program.

[20] See fn. 15.

[21] The 1992-99 data on the 52 Adirondack lakes suggest that nitrogen saturation occurred earlier than the least optimistic of the scenarios modeled by EPA.

Table 4: Percentage of Waters in Three Environmentally Sensitive Areas Projected to Be Acidic in 2040, With Implementation of the 1990 Amendments

Watershed	Percent observed to be acidic in 1984	Time to watershed nitrogen saturation: 50 years	100 years	250 years
Adirondack lakes	19	43	26	15
Mid-Appalachian streams	4	9	5	4
Southern Blue Ridge streams	0	4	0	0

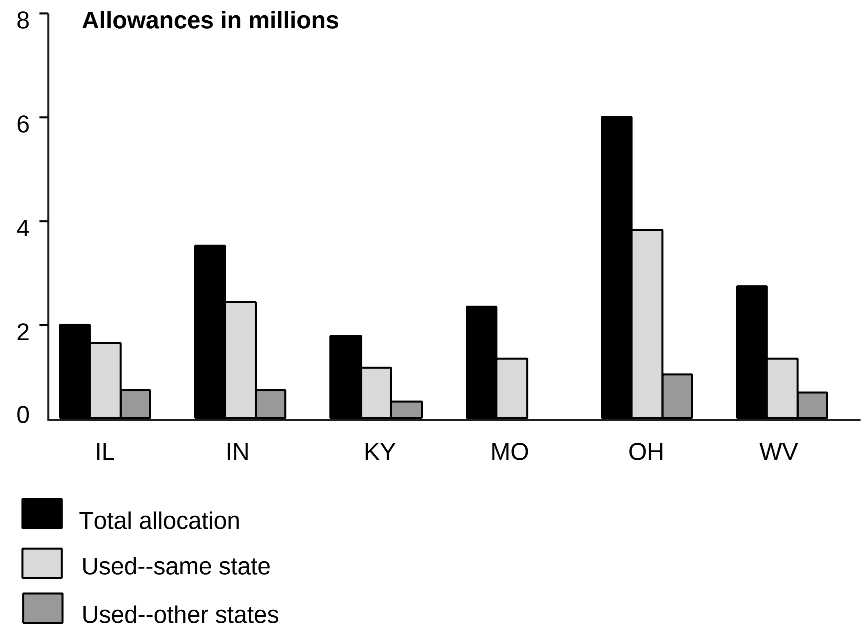
Source: EPA, *Acid Deposition Standard Feasibility Study: Report to Congress*, Oct. 1995.

In Midwestern States, Most Sulfur Dioxide Allowances Were Used in the States Where They Originated

Utilities in the 11 midwestern states used sulfur dioxide allowances from their own states for 11.2 million (81 percent) of the 13.9 million allowances they used from 1995 through 1998, according to EPA's data. The remaining 2.7 million allowances (19 percent) originated in other states. Despite the use of allowances from other states, the midwestern utilities did not use all the allowances allocated to them for these 4 years. Of the 18.5 million allowances originally allocated to them, they did not use 7.3 million allowances, which they may have sold or will be able to use or sell in future years. National trends are similar to trends for the midwestern states.

Although the midwestern states overall used allowances from other states for 19 percent of all the allowances they used, this percentage varied by state. For example, the five states that used the most allowances—Ohio, Indiana, Illinois, Kentucky, and West Virginia–also used the most out-of-state allowances. Ohio, which used more allowances than any other state, used allowances from other states for 19 percent of the 4.4 million allowances it used. Twenty-eight percent of the allowances used by Illinois came from other states, and 30 percent of the allowances used by West Virginia came from other states. Four states did not use any out-of-state allowances. (See fig. 6 for data on the six midwestern states that used the most allowances.)

Figure 6: Allowances Allocated and Used, by Source, for Six Midwestern States, 1995-98



Source: EPA.

Of the 2.7 million out-of-state allowances used by midwestern utilities, about 538,000 (20 percent) originated in the six northeastern and mid-Atlantic states. The largest sources were Pennsylvania (405,000) and New York (70,000).

Similarly, at a broader level, utilities in the 25 states that participated in Phase I of the Acid Rain Program used allowances from their own states for 81 percent of their total and out-of-state allowances for the remaining 19 percent. (These are the same proportions as in the 11 midwestern states.) The reliance on out-of-state allowances varied considerably among states:

In six states, utilities covered all of their sulfur dioxide emissions with allowances that originated in their own states. Among these states, Wisconsin used the most allowances.

In 14 states, utilities covered as much as 24 percent of their emissions with out-of-state allowances. These states included Indiana (19 percent) and Alabama (24 percent).

In the remaining five states, utilities covered between 25 and 45 percent of their emissions with allowances from other states. The highest percentages were in West Virginia (30 percent) and Pennsylvania (45 percent).

(App. II shows the allowances that were used by utilities in the 25 states and by region for 1995 through 1998.)

The use of allowances that originated in other states varied among five geographic regions—Midwest, Southeast, mid-Atlantic, Northeast, and West. For example, 10 percent of the allowances used by the three western states originated in other states, while 36 percent of the allowances used by the three mid-Atlantic states originated in other states.

There was substantial buying and selling of allowances among the participating utilities. In 14 states, utilities sold more allowances to utilities in other states than they purchased from other states. For example, the utilities in Tennessee sold nearly 493,000 more allowances than they purchased. In 10 states, utilities bought more allowances from other states than they sold to other states. For example, utilities in Indiana bought 279,000 more allowances than they sold.[22] In the remaining state, utilities did not sell any allowances to, or buy any allowances from, other states. The net flow of allowances by state and region is shown in appendix III.

Because the utilities that participated in Phase I reduced their sulfur dioxide emissions more than the minimum required, they did not use as many allowances as they were allocated for the first 4 years of the program. Specifically, of the 30.2 million allowances allocated to utilities nationwide, almost 8.7 million, or 29 percent, of the allowances were not used. These unused allowances can be used to offset sulfur dioxide emissions in future years.

Observations

In the first 4 years following implementation of the Acid Rain Program, sulfur dioxide emissions generally continued their long-term decline, while nitrogen oxide emissions generally remained stable. Moreover, sulfate deposition in the eastern states and in the three environmentally sensitive areas generally declined, which is consistent with trends in emissions.

[22]The net flow of allowances for a state is the difference between the number of allowances sold to utilities in other states and the number of allowances bought from utilities in other states.

Finally, the level of sulfates in a sample of lakes in the Adirondack Mountains generally declined, which is consistent with the trend in sulfate deposition. However, although nitrate deposition was generally stable, the level of nitrates in these lakes often increased. This apparently occurred because the vegetation and soils surrounding the lakes have lost some of the capacity to use nitrogen. These trends highlight the significance of nitrogen oxide emissions and the resulting nitrogen deposition, which may not have been fully appreciated when the 1990 amendments were being drafted. Because those amendments require relatively little reduction in nitrogen oxide emissions, the prospects are uncertain for the recovery of already acidified lakes and for preventing further acidification.

Agency Comments

We provided a draft of this report to EPA for review and comment. EPA generally agreed with the facts presented in the report. Also, EPA said that the report successfully linked together several complex subjects and explained them in an understandable way. (App. IV contains EPA's comments.) Finally, EPA provided technical clarifications, which we incorporated as appropriate.

Scope and Methodology

To analyze the trends in national sulfur dioxide and nitrogen oxide emissions, deposition levels in the eastern United States, and the environmental impact of deposition on sensitive areas, we interviewed officials from, and reviewed studies and other documents prepared by, federal agencies that have a role in managing or supporting the Acid Rain Program. These agencies included EPA, the Forest Service, the National Oceanic and Atmospheric Administration, the National Park Service, the U.S. Geological Survey, and the National Acid Precipitation Assessment Program. We also interviewed representatives of, and reviewed studies and other documents prepared by, advocacy, environmental, and research organizations, including the Adirondack Council, Environmental Defense Fund, Natural Resources Defense Council, Resources for the Future, Sierra Club, and Trout Unlimited. Regarding the data from various monitoring networks that measure acid deposition levels and the impact on various ecosystems, we interviewed researchers from, and reviewed studies and other documents prepared by, the Adirondack Lakes Survey Corporation, Appalachian State University, Institute of Ecosystem Studies, National Atmospheric Deposition Program, and Pennsylvania State University, who have analyzed the data from the networks and conducted research.

Regarding the trading of sulfur dioxide allowances, we obtained and analyzed EPA data for calendar years 1995 through 1998. We calculated the number of allowances that were used, as well as the number that were not used and can be used in future years. We also calculated the number of used allowances that originated in the state where they were used and the number that originated in another state.

Although we did not independently verify the reliability of the data we obtained from EPA or other sources, these are the data sources that are generally used by EPA, other federal agencies, and other analysts. We performed our review from May 1999 through February 2000 in accordance with generally accepted government auditing standards.

As arranged with your offices, unless you publicly announce its contents earlier, we plan no further distribution of this report until 7 days after the date of this letter. At that time, we will send copies of this report to Senator Robert C. Smith and Senator Max Baucus, in their capacities as Chairman and Ranking Minority Member of the Senate Committee on Environment and Public Works; Representative Tom Bliley and Representative John D. Dingell, in their capacities as Chairman and Ranking Minority Member of the House Committee on Commerce; other interested Members of Congress; and the Honorable Carol M. Browner, Administrator, EPA. We will also make copies available to others upon request.

If you have any questions about this report, please contact me or David Marwick at (202) 512-6111. Key contributors to this report were Joseph L. Turlington, DeAndrea Michelle Leach, Richard A. Frankel, and Susan M. Pandy.

Peter F. Guerrero
Director, Environmental
Protection Issues

Effect of Acid Rain on Human Health and Selected Ecosystems and Anticipated Recovery Benefits

Human health and ecosystem	Effects	Recovery benefits
Human health	In the atmosphere, sulfur dioxide and nitrogen oxides become sulfate and nitrate aerosols, which increase morbidity and mortality from lung disorders, such as asthma and bronchitis, and impacts to the cardiovascular system.	Decrease emergency room visits, hospital admissions, and deaths.
Surface waters	Acidic surface waters decrease the survivability of animal life in lakes and streams and in the more severe instances eliminate some or all types of fish and other organisms.	Reduce the acidic levels of surface waters and restore animal life to the more severely damaged lakes and streams.
Forests	Acid deposition contributes to forest degradation by impairing trees' growth and increasing their susceptibility to winter injury, insect infestation, and drought. It also causes leaching and depletion of natural nutrients in forest soil.	Reduce stress on trees, thereby reducing the effects of winter injury, insect infestation, and drought, and reduce the leaching of soil nutrients, thereby improving overall forest health.
Materials	Acid deposition contributes to the corrosion and deterioration of buildings, cultural objects, and cars, which decreases their value and increases costs of correcting and repairing damage.	Reduce the damage to buildings, cultural objects, and cars, and reduce the costs of correcting and repairing future damage.
Visibility	In the atmosphere, sulfur dioxide and nitrogen oxides form sulfate and nitrate particles, which impair visibility and affect the enjoyment of national parks and other scenic views.	Extend the distance and increase the clarity at which scenery can be viewed, thus reducing limited and hazy scenes and increasing the enjoyment of national parks and other vistas.

Allowances Used by the 25 States Participating in Phase I of the Acid Rain Program, 1995-98

Allowances in thousands

		Allowances used				
Region/state	**Allowances allocated**	**Total**	**Same state**	**Percent**	**Other states**	**Percent**
Midwest						
Illinois	1,781.1	1,955.4	1,417.3	72	538.1	28
Indiana	3,286.8	2,715.1	2,205.3	81	509.8	19
Iowa	162.2	90.0	88.6	98	1.4	2
Kansas	110.4	58.5	58.5	100	0	0
Kentucky	1,565.0	1,286.7	963.9	75	322.8	25
Michigan	342.0	234.7	234.7	100	0	0
Minnesota	90.7	52.4	52.4	100	0	0
Missouri	2,145.7	1,114.6	1,108.8	99	5.8	1
Ohio	5,767.5	4,404.1	3,587.3	81	816.8	19
West Virginia	2,505.6	1,615.1	1,131.5	70	483.6	30
Wisconsin	753.6	387.3	387.3	100	0	0
Subtotal	**18,510.4**	**13,913.9**	**11,235.6**	**81**	**2,678.3**	**19**
Southeast						
Alabama	961.0	677.2	514.7	76	162.5	24
Florida	728.6	571.2	490.9	86	80.3	14
Georgia	2,981.6	1,620.7	1,577.6	97	43.2	3
Mississippi	251.0	281.7	251.9	89	29.7	11
Tennessee	2,090.7	1,090.4	1,087.4	100	3.0	[a]
Subtotal	**7,012.9**	**4,241.2**	**3,922.5**	**92**	**318.7**	**8**
Mid-Atlantic						
Maryland	638.4	584.0	517.7	89	66.3	11
New Jersey	112.9	76.1	73.2	96	2.9	4
Pennsylvania	2,640.2	1,947.1	1,074.5	55	872.6	45
Subtotal	**3,391.5**	**2,607.2**	**1,665.4**	**64**	**941.8**	**36**
Northeast						
Massachusetts[b]	115.9	180.1	170.0	94	10.0	6
New Hampshire	171.2	177.6	128.9	73	48.7	27
New York	866.1	374.1	293.8	79	80.3	21
Subtotal	**1,153.3**	**731.8**	**592.8**	**81**	**139.0**	**19**
West						
California	4.8	0	0	0	0	0

Continued

Region/state	Allowances allocated	Allowances used				
		Total	Same state	Percent	Other states	Percent
Utah	2.6	[c]	[c]	100	0	0
Wyoming	135.6	60.4	54.0	90	6.3	10
Subtotal	**143.0**	**60.4**	**54.0**	**90**	**6.3**	**10**
Total	**30,211.1**	**21,554.5**	**17,470.3**	**81**	**4,084.2**	**19**

Continued from Previous Page

Note: Individual amounts may not sum to totals and subtotals because of independent rounding.

[a]Amount rounds to less than 0.5 percent.

[b]Power plants in Massachusetts that voluntarily participated in Phase I were affected by that state's cap on company emissions. Because the Environmental Protection Agency (EPA) did not consider the cap when it allocated allowances for these power plants, approximately 54,000 allowances were deducted from future year accounts. Therefore, the utilities in Massachusetts used more in-state allowances during 1995-98 than they were allocated.

[c]Amount rounds to less than 0.5 thousand.

Source: EPA.

Net Flow of Allowances Used by the 25 States Participating in Phase I of the Acid Rain Program, 1995-98

Allowances in thousands

	Allowances used		
Region/state	Total inflow (acquired from other states)	Total outflow (sold to other states)	Net flow [a]
Midwest			
Illinois	538.1	101.9	436.2
Indiana	509.8	230.4	279.4
Iowa	1.4	0	1.4
Kansas	0	10.1	-10.1
Kentucky	322.8	111.3	211.5
Michigan	0	0	0
Minnesota	0	b	b
Missouri	5.8	141.4	-135.6
Ohio	816.8	720.1	96.7
West Virginia	483.6	711.4	-227.8
Wisconsin	0	93.6	-93.6
Subtotal	**2,678.3**	**2,120.2**	**558.1**
Southeast			
Alabama	162.5	94.8	67.6
Florida	80.3	92.4	-12.2
Georgia	43.2	268.4	-225.2
Mississippi	29.7	7.6	22.1
Tennessee	3.0	495.9	-492.9
Subtotal	**318.7**	**959.2**	**-640.5**
Mid-Atlantic			
Maryland	66.3	28.6	37.7
New Jersey	2.9	14.6	-11.7
Pennsylvania	872.6	627.3	245.3
Subtotal	**941.8**	**670.5**	**271.3**
Northeast			
Massachusetts	10.0	40.6	-30.6
New Hampshire	48.7	19.7	29.0
New York	80.3	201.6	-121.3
Subtotal	**139.0**	**261.9**	**-122.9**

Continued

	Allowances used		
Region/state	**Total inflow (acquired from other states)**	**Total outflow (sold to other states)**	**Net flow [a]**
West			
California	0	4.6	-4.6
Utah	0	0.9	-0.9
Wyoming	6.3	66.9	-60.5
Subtotal	6.3	72.4	-66.0
Total	**4,084.2**	**4,084.2**	**0**

Continued from Previous Page

Note: Individual amounts may not sum to totals and subtotals because of independent rounding.

[a]A positive number in this column indicates that the utilities in a given state acquired more allowances from utilities in other states than they sold to utilities in other states; a negative number indicates the reverse.

[b]Amount rounds to less than 0.5 thousand.

Source: EPA.

Comments From the Environmental Protection Agency

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF
AIR AND RADIATION

MEMORANDUM

TO: Peter F. Guerrero, Director
Environmental Protection Issues, U.S. General Accounting Office

FROM: Brian J. McLean, Director
Clean Air Markets Division, Office of Atmospheric Programs

DATE: February 25, 2000

Enclosed please find the Environmental Protection Agency's response to your report entitled *Acid Rain: Emissions Trends and Effects in the Eastern United States*. Thank you for the opportunity to review and provide our comments to you.

Enclosure

EPA Response to GAO Report *ACID RAIN - Emissions Trends and Effects in the Eastern United States*

EPA generally agrees with the facts presented in the report. GAO has successfully linked together several complex subjects (emissions, deposition, ecological response) and explained them in an understandable way. First, the report identifies emission reductions in total sulfur dioxide emission levels since 1990 and highlights the significant drop in SO2 emissions in 1995, the year that Phase I of the Acid Rain Program began. As indicated in this report, the drop in SO2 emissions was accompanied by significant reductions in both wet and dry sulfur deposition and in sulfate levels in sensitive aquatic resources in the northeastern United States. Second, GAO identifies different trends in NOx emissions and subsequent impacts on deposition and the environment. While there has been a reduction in NOx emission rates from power generation since 1990, the steady increase in electricity production has resulted in only a small reduction in NOx emissions. Now, as the over 2 million ton reduction under Phase II of the Acid Rain NOx Program is being implemented, the Agency expects to see the impact of those reductions in the short-term. However, without a cap on emissions, expected continued increases in demand for electricity will offset some portion of the 2 million ton reduction.

As stated in the report, EPA believes that small changes in concentrations or deposition over multi-year periods may not actually constitute a significant trend. For example, given the currently limited period of time between implementation of the Acid Rain Program and atmospheric deposition analyses referenced here, large changes (such as the decrease in sulfur deposition) almost certainly indicate a decreasing trend in sulfur deposition, whereas small changes (such as the increase in nitrogen deposition) may be largely due to natural climatic variations and may not accurately reflect the actual trend in deposition of nitrogen. As additional years of data are added to these time-trend analyses, EPA will be able to provide further information on the statistical significance of these trends.

EPA agrees with GAO's conclusions regarding continued impact of nitrogen on the environment. GAO referenced EPA's 1995 Report to Congress - Acid Deposition Standard Feasibility Study. However, one major conclusion of that report which is not clearly identified is that the role of nitrogen in acidification (chronic and episodic) increases as the time to saturation is reduced and that in the Adirondacks reducing sulfur deposition alone under the Clean Air Act Amendments may not result in recovery of all acidic lakes. In fact, nitrogen could begin to offset improvements in water quality due to sulfur reductions. In that report, EPA concluded that further reductions in sulfur and nitrogen deposition may be necessary to protect the most sensitive ecosystems.

EPA agrees with GAO's statements concerning SO2 emission allowance transfers. It is useful, however, to point out that the utilities in the 11 Midwestern states considered were issued 18.5 million allowances (1995 through 1998) in accordance with the Clean Air Act and, thus, were authorized to emit 18.5 million tons of SO2. However, they emitted only 13.9 million tons of SO2 during that time. Of the 13.9 million allowances surrendered to cover those emissions, 11.2 million (81 percent) originated in those 11 states, and 2.7 million originated in other states, of which 538,000 originated in six northeastern and mid-Atlantic states, as identified by GAO.

2

Overall, the contribution of allowances from the northeastern and mid-Atlantic states to the Midwestern states was small compared to the 18.5 million provided by the Act. EPA strongly believes that the SO2 allowance trading program continues to provide a cost-effective means of achieving large scale emission reductions and has resulted in significant environmental benefits.

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