

Clean Air Interstate Rule, Acid Rain Program, and Former NO_x Budget Trading Program

Environmental and Health Results Report

Program Basics

The Clean Air Interstate Rule (CAIR) and the Acid Rain Program (ARP) are both cap and trade programs designed to reduce emissions of sulfur dioxide (SO₂) and nitrogen oxides (NO_x) from power plants.

The ARP, established under Title IV of the 1990 Clean Air Act (CAA) Amendments, requires major emission reductions of SO₂ and NO_x, the primary precursors of acid rain, from the power sector. The SO₂ program sets a permanent cap on the total amount of SO₂ that may be emitted by electric generating units (EGUs) in the contiguous United States. The program is phased in, with the final 2010 SO₂ cap set at 8.95 million tons, a level of about one-half of the emissions from the power sector in 1980. NO_x reductions under the ARP are achieved through a program that applies to a subset of coal-fired EGUs and is closer to a traditional, rate-based regulatory system. Since the program began in 1995, the ARP has achieved significant emission reductions. For more information on the ARP, please visit the ARP website at epa.gov/airmarkets/progsregs/arp/index.html.

The NO_x Budget Trading Program (NBP) operated from 2003 to 2008. The NBP was a cap and trade program that required NO_x emission reductions from power plants and industrial units in the eastern U.S. during the summer months. For more information on the NBP, please visit the NO_x Budget Trading Program/NO_x SIP Call website at epa.gov/airmarkets/progsregs/nox/sip.html.

CAIR addresses regional interstate transport of ozone and fine particle pollution. CAIR requires certain eastern states to limit annual emissions of NO_x and SO₂, which contribute to the formation of smog (ground-level ozone) and soot (fine particulate matter). It also requires certain states to

At a Glance: Environmental and Health Results in 2011

By reducing the precursors (SO₂ and NO_x) to PM_{2.5} and ozone formation, emission reductions achieved by the ARP, NPB, and CAIR significantly benefit human health and welfare.

Air Quality: Between 1989 to 1991 and 2009 to 2011, average ambient sulfate concentrations have decreased by 56 percent in the Mid-Atlantic, 53 percent in the Midwest, 60 percent in the Northeast, and 55 percent in the Southeast. In CAIR states, average 1-hour ozone concentrations decreased by 18 percent between the same three-year periods.

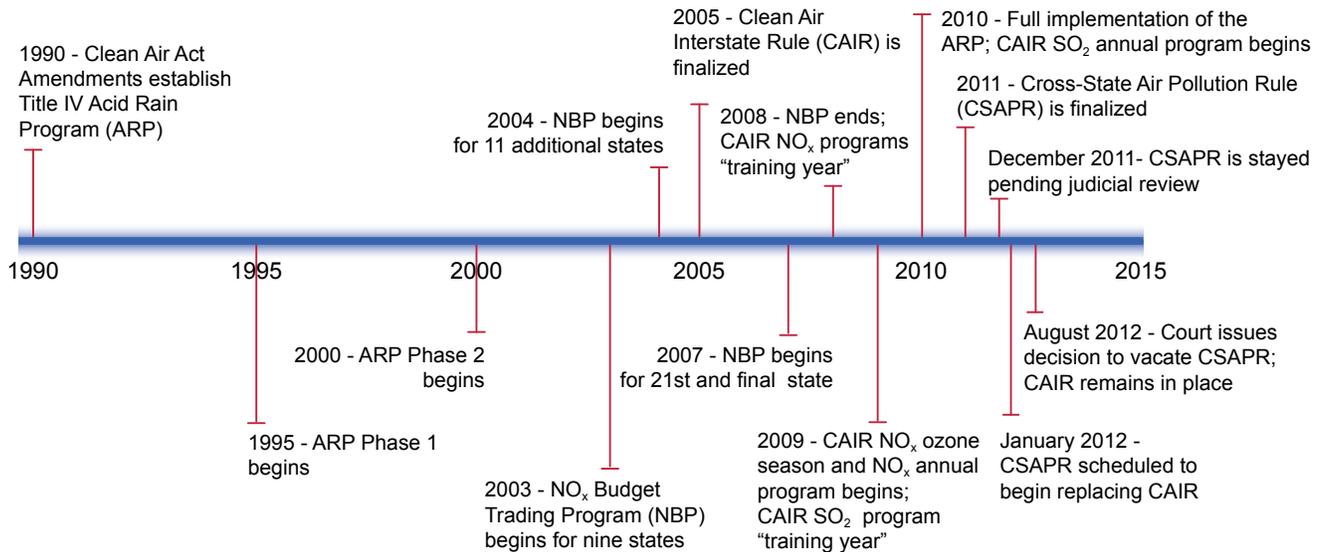
Acid Deposition: Between the 1989 to 1991 and 2009 to 2011 observation periods, regional decreases in wet deposition of sulfate across the Eastern United States averaged 55 percent.

Surface Water Chemistry: Levels of Acid Neutralizing Capacity (ANC), the ability of a water body to neutralize acid deposition, have increased significantly from 1990 in lake and stream long-term monitoring sites in the Adirondack Mountains and the Northern Appalachian Plateau. These increasing ANC levels indicate trends toward recovery from acidification.

limit ozone season NO_x emissions, which contribute to the formation of smog during the summer ozone season (May through September). CAIR includes three separate cap and trade programs to achieve the required reductions: the CAIR NO_x ozone season trading program, the CAIR NO_x annual trading program, and the CAIR SO₂ annual trading program. The CAIR NO_x ozone season and annual programs began in 2009, while the CAIR SO₂ annual program began in 2010. The reduction in ozone and fine particles (PM_{2.5}) formation resulting from implementation of



Figure 1: History of CAIR, ARP, CSAPR, and Former NBP



Source: EPA, 2013

CAIR provides health benefits as well as improved visibility in national parks and improvements in freshwater aquatic ecosystems in the eastern U.S. For more information on CAIR, please visit the CAIR website at <epa.gov/airmarkets/progsregs/cair/>.

CSAPR and Litigation

The Cross-State Air Pollution Rule (CSAPR) was promulgated in 2011 to improve air quality by reducing NO_x and SO₂ emissions that cross state lines and contribute significantly to ozone and fine particle pollution in downwind states. CSAPR required 28 states in the eastern half of the U.S. to reduce power plant emissions through participation in new cap and trade programs for ozone season NO_x, annual NO_x, and annual SO₂. The CSAPR trading programs were scheduled to replace the CAIR trading programs starting in January 2012. However, the U.S. Court of Appeals for the District of Columbia Circuit stayed CSAPR before it took effect, and in August 2012 the court issued an opinion vacating the rule and ordering EPA to continue administering CAIR pending promulgation of a valid replacement rule.¹ The court subsequently denied all petitions for rehearing of its opinion, and the United States has not yet decided whether to seek Supreme Court review. In the meantime, as the court stated in its August opinion, CAIR remains in place and states and affected sources

are expected to comply with that rule. For more information on CSAPR, please visit the CSAPR website at <epa.gov/crossstaterule/index.html>.

Figure 1 contains important milestones for CAIR, ARP, CSAPR, and the former NBP.

CAIR, ARP, and NBP Affected States

The ARP is a nationwide program affecting large fossil fuel-fired power plants across the country. CAIR covers 27 eastern states and the District of Columbia (D.C.) and requires reductions in annual emissions of SO₂ and NO_x from 24 states and D.C. (to achieve improvements in fine particle pollution in downwind areas) and emission reductions of NO_x during the ozone season from 25 states and D.C. (to achieve improvements in ozone pollution in downwind areas). The former NBP affected 20 eastern states and D.C. State coverage for CAIR, ARP, and NBP is shown in Figure 2 on page 3.

2011 Progress Reports

Each year EPA releases reports summarizing progress under both CAIR and the ARP. In the 2011 reports, EPA presents emissions and compliance data for both CAIR and the ARP to show reductions in power sector emissions of SO₂ and NO_x and the effect of these programs on air quality and the environment. While several other programs contribute to NO_x and SO₂ emission reductions

and improved air quality (e.g., mobile source emission control programs), this series of reports focuses on achievements related to emission reductions at power sector sources under CAIR, the ARP, and the former NBP.

The first report in this series, the CAIR, ARP, and Former NBP 2011 SO₂ and NO_x Emissions, Compliance, and Market Analyses Report, was released in December 2012 and presents 2011 data on combined emission reductions and compliance results for CAIR and the ARP. It also presented some historic NBP emissions data and evaluated shared progress under these programs in 2011 by analyzing emission reductions and market activity. This report provides further 2011 trends analysis by comparing changes in emissions to changes in air quality, acid deposition, and surface water chemistry.

Air Quality

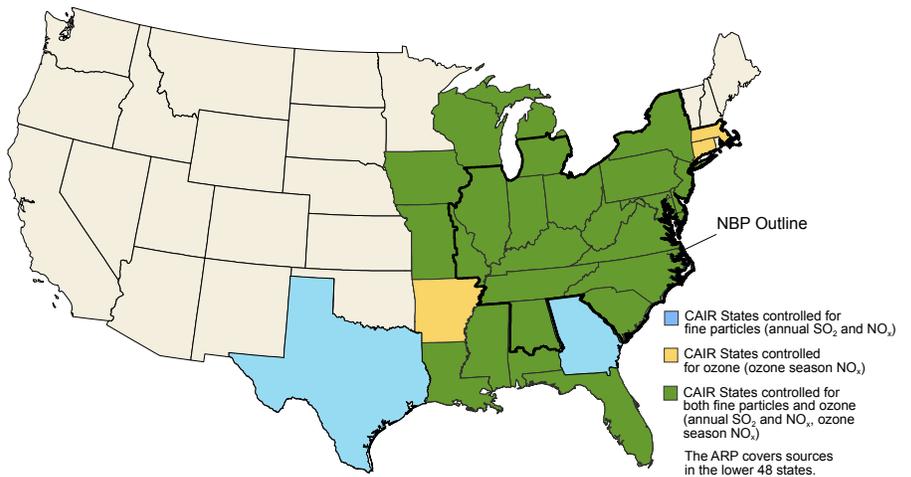
To evaluate the impact of emission reductions on the environment, scientists and policymakers use data collected from long-term national air quality and deposition monitoring networks (see text box). These complementary, long-term monitoring networks provide information on a variety of indicators necessary for tracking temporal and spatial trends in regional air quality and acid deposition.

Sulfur Dioxide

SO₂ is one of a group of highly reactive gases known as “oxides of sulfur.” The largest sources of SO₂ emissions are from fossil fuel combustion at power plants (65 percent) and other industrial facilities (16 percent). Smaller sources of SO₂ emissions include industrial processes such as extracting metal from ore, and the burning of high sulfur containing fuels by locomotives, large ships, and non-road equipment. SO₂ is linked with a number of adverse health effects on the respiratory system.

Data collected from monitoring networks show that the decline in SO₂ emissions from the power industry has improved air quality. Based on EPA’s latest air trends data, the national composite average of SO₂ annual mean ambient concentrations decreased 84 percent between 1980 and 2011, as shown in Figure 3 on page 3 (based on state, local, and EPA monitoring sites located primarily in

Figure 2: CAIR, ARP, and NBP States



Source: EPA, 2012

About Long-term Ambient and Deposition Monitoring Networks

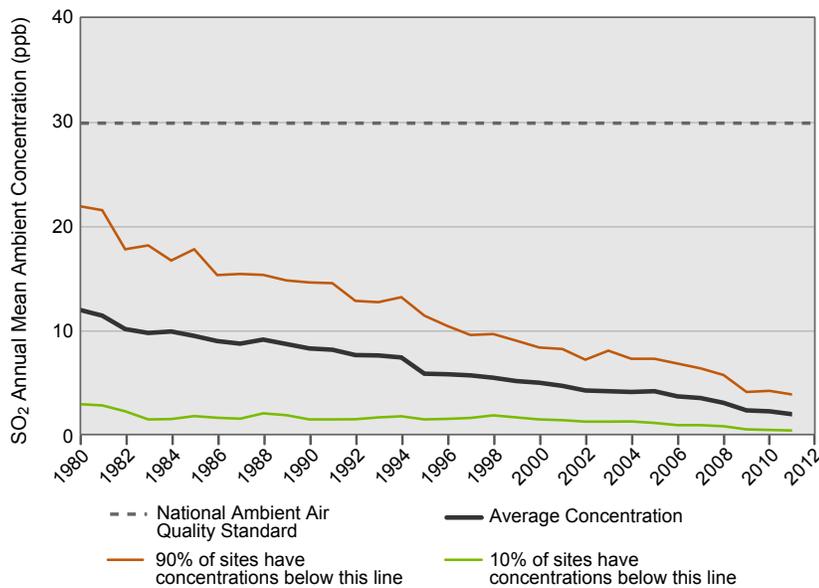
The Clean Air Status and Trends Network (CASTNET) provides long-term monitoring of air quality in rural areas to determine trends in regional atmospheric nitrogen, sulfur, and ozone concentrations and deposition fluxes (the rate of particles and gases being deposited to a surface) of sulfur and nitrogen pollutants in order to evaluate the effectiveness of national and regional air pollution control programs. CASTNET operates more than 80 regional sites throughout the contiguous United States, Alaska, and Canada. Sites are located in areas where urban influences are minimal. Information and data from CASTNET are available at the CASTNET website at <www.epa.gov/castnet>.

AQS contains ambient air pollution data collected by EPA, state, local, and tribal air pollution control agencies from thousands of monitoring stations. AQS also contains meteorological data, descriptive information about each monitoring station (including its geographic location and its operator), and data quality assurance/quality control information. Information and data from AQS are available at the Air Quality System website at <epa.gov/ttn/airs/airsaqs>.

The National Atmospheric Deposition Program/National Trends Network (NADP/NTN) is a nationwide, long-term network tracking the chemistry of precipitation. NADP/NTN provides concentration and wet deposition data on hydrogen ion (acidity as pH), sulfate, nitrate, ammonium, chloride, and base cations. NADP/NTN has grown to more than 250 sites spanning the continental United States, Alaska, Puerto Rico, and the Virgin Islands. Information and data from NADP/NTN are available at the NADP’s website at <nadp.sws.uiuc.edu>.

urban areas). The two largest single-year reductions (over 20 percent reduction each) occurred in the first year of the ARP, between 1994 and 1995, and recently between 2008 and 2009, just prior to

Figure 3: National SO₂ Air Quality, 1980–2011



Source: EPA, 2013

the start of the CAIR SO₂ program. These trends are consistent with the regional ambient air quality trends observed in the Clean Air Status and Trends Network (CASTNET).

Dramatic regional improvements in SO₂ and ambient sulfate concentrations were observed following implementation of Phase I of the ARP during the late 1990s at CASTNET sites throughout the eastern United States, and these improvements continue today. Analyses of regional monitoring data from CASTNET show the geographic pattern of SO₂ and airborne sulfate in the eastern United States. Three-year mean annual concentrations of SO₂ and sulfate from CASTNET long-term monitoring sites are compared from 1989 to 1991 (before implementation of the ARP) and 2009 to 2011 (most recent available data) in tabular form in Table 1 on page 5.

The average annual ambient concentrations of SO₂ from 1989 to 1991 were highest in western Pennsylvania and along the Ohio River Valley. There was a significant decline in those concentrations in nearly all affected areas after implementation of the ARP and other programs.

Like SO₂ concentrations, the highest average annual ambient sulfate concentrations from 1989 to 1991 were observed in western Pennsylvania and along the Ohio River Valley. Most of the eastern United States experienced annual ambient sulfate concentrations greater than 5 micrograms per cubic meter (µg/m³).

Ambient sulfate concentrations have also decreased since the ARP was implemented, with average concentrations decreasing by 53 to 60 percent in observed regions (see Table 1 on page 5). Both the magnitude and spatial extent of the highest concentrations have dramatically declined, with the largest decreases observed along the Ohio River Valley.

Nitrogen Oxides

NO_x is a group of highly reactive gases including nitrogen dioxide, nitrous acid, and nitric acid. In addition to contributing to the formation of ground-level ozone and PM_{2.5}, NO_x is linked with a number of adverse health effects on the respiratory system.

From 2009 to 2011, reductions in NO_x emissions during the ozone season from power plants under the NO_x SIP Call, ARP, and CAIR have continued to contribute to significant regional improvements in ambient total nitrate (NO₃⁻ plus HNO₃) concentrations. For instance, annual mean ambient total nitrate concentrations for 2009 to 2011 in the Mid-Atlantic region were 48 percent less than the annual mean concentration in 1989 to 1991 (see Table 1 on page 5).

Although the ARP and CAIR NO_x programs have contributed to significant NO_x reductions, emissions from other sources (such as motor vehicles and agriculture) contribute to ambient nitrate concentrations in many areas. Ambient nitrate levels can also be affected by emissions transported via air currents over wide regions.

Table 1: Regional Changes in Air Quality and Deposition of Sulfur and Nitrogen Compounds, 1989–1991 versus 2009–2011, from Rural Monitoring Networks

Measurement	Region	Annual Average, 1989–1991	Annual Average, 2009–2011	Percent Change	Number of Sites
Ambient SO ₂ Concentration (micrograms per cubic meter, µg/m ³)	Mid-Atlantic	13	3	-77	12
	Midwest	11	3	-73	10
	Northeast	5.5	1.1	-80	3
	Southeast	5.1	1.3	-75	8
Ambient Particulate Sulfate Concentration (µg/m ³)	Mid-Atlantic	6.3	2.8	-56	12
	Midwest	5.8	2.7	-53	10
	Northeast	3.5	1.4	-60	3
	Southeast	5.5	2.5	-55	8
Ambient Total Nitrate Concentration (Nitrate + Nitric Acid) (µg/m ³)	Mid-Atlantic	3.3	1.7	-48	12
	Midwest	4.6	3	-35	10
	Northeast	1.8	0.8	-56	3
	Southeast	2.2	1.3	-41	8
Dry Inorganic Nitrogen Deposition (kilograms nitrogen per hectare, kg-N/ha)	Mid-Atlantic	2.5	1.3	-48	12
	Midwest	2.5	1.5	-40	10
	Northeast	1.4	0.5	-64	3
	Southeast	1.7	0.9	-47	8
Total Inorganic Nitrogen Deposition (kg-N/ha)	Mid-Atlantic	8.8	3.7	-58	12
	Midwest	8.8	4.7	-47	10
	Northeast	6.7	2.5	-63	3
	Southeast	6.4	3.3	-48	8
Dry Sulfur Deposition (kilograms sulfur per hectare, kg-S/ha)	Mid-Atlantic	7	1.9	-73	12
	Midwest	6.6	2.1	-68	10
	Northeast	3.0	0.7	-77	3
	Southeast	3.1	1.0	-68	8
Total Sulfur Deposition (kg-S/ha)	Mid-Atlantic	16	4	-75	12
	Midwest	15	5	-67	10
	Northeast	10	2	-76	3
	Southeast	10	3	-70	8
Wet Nitrogen Deposition from Inorganic Nitrogen (kg-N/ha)	Mid-Atlantic	6.2	4.3	-31	11
	Midwest	5.8	4.9	-16	27
	Northeast	5.6	3.6	-36	17
	Southeast	4.4	3.6	-18	23
Wet Sulfur Deposition from Sulfate (kg-S/ha)	Mid-Atlantic	9.2	3.9	-58	11
	Midwest	7.1	3.4	-52	27
	Northeast	7.5	3	-60	17
	Southeast	6.1	3	-51	23

Notes:

- Averages are the arithmetic mean of all sites in a region that were present and met the completeness criteria in both averaging periods. Thus, average concentrations for 1989 to 1991 may differ from past reports.
- Total deposition is estimated from raw measurement data, not rounded, and may not equal the sum of dry and wet deposition.
- Percent change and values in bold indicates that differences were statistically significant at the 95 percent confidence level. Changes that are not statistically significant may be unduly influenced by measurements at only a few locations or large variability in measurements.

Source: EPA, 2013

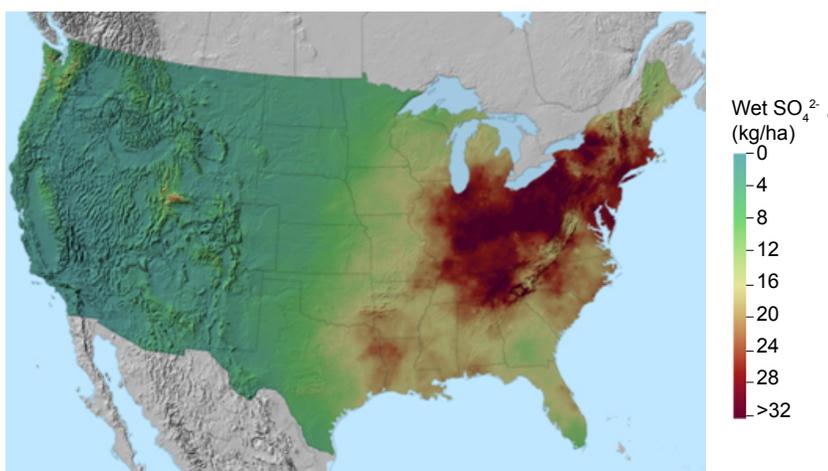
Acid Deposition

As SO_2 and NO_x gases react in the atmosphere with water, oxygen, and other chemicals, they form various acidic compounds that get deposited to the ground in the form of wet and dry acid deposition. Trends in National Atmospheric Deposition Program/National Trends Network (NADP/NTN) monitoring network data show significant improvements in the primary acid deposition indicators. For example, wet sulfate deposition (sulfate that falls to the earth through rain, snow, and fog) has decreased since the implementation of the ARP in much of the Ohio River Valley and

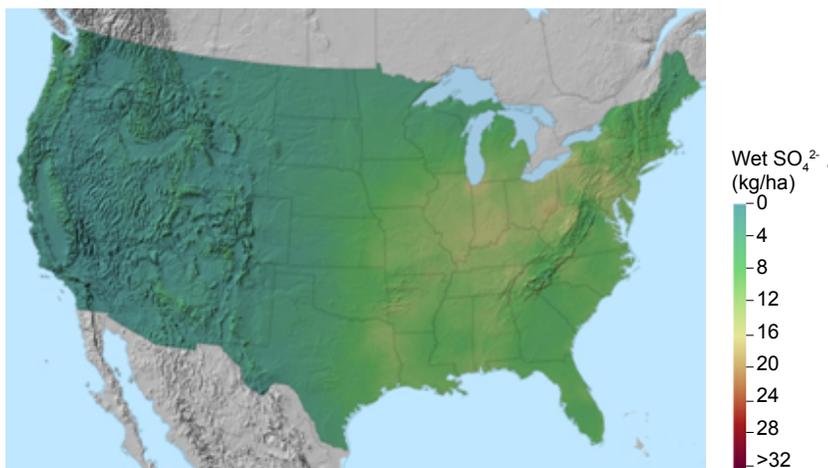
northeastern United States. Some of the greatest reductions have occurred in the mid-Appalachian region, including Maryland, New York, West Virginia, Virginia, and most of Pennsylvania. Other less dramatic reductions have been observed across much of New England, portions of the southern Appalachian Mountains, and some areas of the Midwest. Between the 1989 to 1991 and 2009 to 2011 observation periods, decreases in wet deposition of sulfate averaged more than 55 percent for the eastern United States (see Table 1 on page 5 and Figure 4).

Figure 4: Three-Year Mean Wet Sulfate Deposition

1989–1991



2009–2011



Source: EPA, 2013

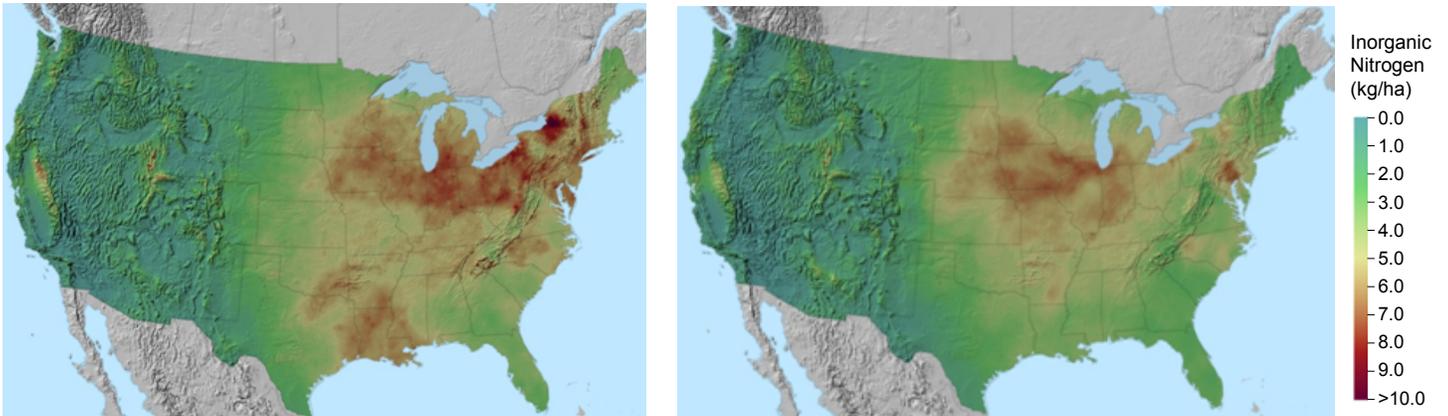
Along with wet sulfate deposition, wet sulfate concentrations have also decreased by similar percentages. A strong correlation between large-scale SO_2 emission reductions and large reductions in sulfate concentrations in precipitation has been noted in the Northeast, one of the areas most affected by acid deposition. The reduction in total sulfur deposition (wet plus dry) has been of similar magnitude as that of wet deposition in the Mid-Atlantic and Midwest, with reductions of 75 and 67 percent, respectively (see Table 1 on page 5). Because continuous data records are available from only a few sites in the Northeast, it is unclear if the observed reductions in total deposition are representative for that region.

A principal reason for reduced sulfate deposition in the Northeast is a reduction in the long-range transport of sulfate from emission sources located in the Ohio River Valley. The reductions in sulfate documented in the Northeast, particularly across New England and portions of New York, were also affected by SO_2 emission reductions in eastern Canada. NADP data indicate that similar reductions in precipitation acidity, expressed as hydrogen ion (H^+) concentrations, occurred concurrently with sulfate reductions, with reductions of nearly 70 percent over much of the East.

Figure 5: Three-Year Mean Wet Inorganic Nitrogen Deposition

1989–1991

2009–2011



Source: EPA, 2013

Reductions in nitrogen deposition recorded since the early 1990s have been less pronounced than those for sulfur. As noted earlier, emission changes from source categories other than ARP and CAIR sources significantly affect air concentrations and deposition of nitrogen.

Inorganic nitrogen in wet deposition decreased comparably in the Mid-Atlantic and Northeast (see Figure 5). Decreases in dry and total inorganic nitrogen deposition at CASTNET sites have generally been greater than that of wet deposition, with a 58 and 47 percent decrease in total nitrogen deposition for the Mid-Atlantic and Midwest, respectively (see Table 1 on page 5).



Photo credit: Sue Capone, Adirondack Lakes Survey Corporation

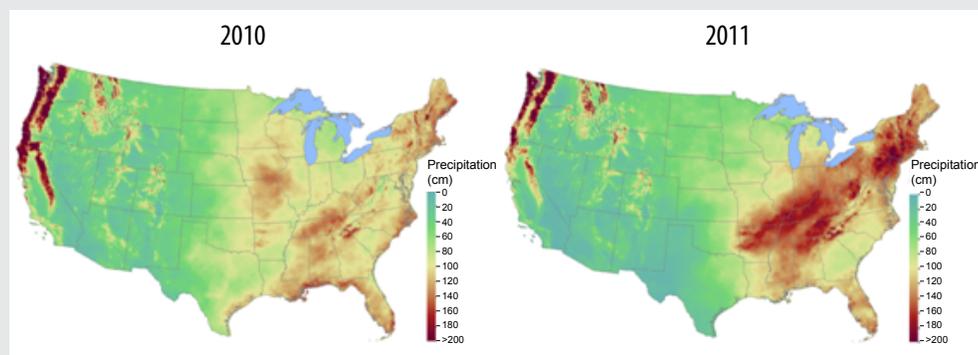
2011 Wet Inorganic Nitrogen Deposition

In 2011, increases in precipitation in the Midwest, Mid-Atlantic and New England regions caused a significant increase in wet deposition of inorganic nitrogen. The upper Mississippi River basin was especially hard hit, with a nearly 300% increase in precipitation over normal levels in the spring and summer, and some states in the Mid-Atlantic and New England region experienced their highest precipitation levels ever recorded. Figure 6 shows the increase in precipitation from 2010 to 2011, as measured by NADP/NTN and the Parameter-elevation Regressions on Independent Slopes Model (PRISM).

To assess trends in concentrations in precipitation, EPA typically examines 3-year averages to mitigate the effects of meteorological inter-annual variability. However, the extreme weather in 2011 highlights the impacts meteorology can have on deposition fluxes. In the Eastern US, there was a 39 percent increase in wet inorganic nitrogen ($\text{NH}_4 + \text{NO}_3$) deposition between 2010 and 2011 (see Figure 7). Precipitation weighted mean nitrogen concentrations increased 14 percent while dry nitrogen deposition decreased 8 percent between 2010 and 2011 (see Figure 8). These trends indicate that the large increase in total nitrogen deposition (30 percent) is due to the increased amount of nitrogen in wet deposition alone.

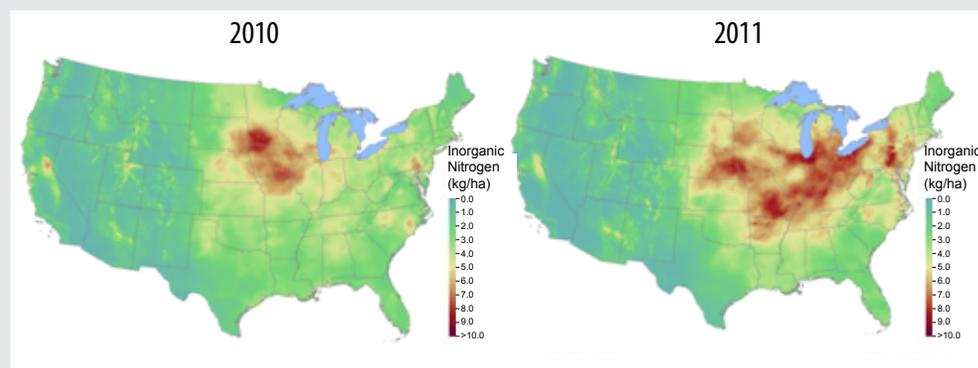
Eastern CASTNET reference sites show a slight decrease (5 percent) in ambient concentrations of total nitrate ($\text{HNO}_3 + \text{NO}_3$) from 2010 to 2011, which indicates the significant increase in wet inorganic nitrogen deposition was not due to an increase in ambient concentrations. The increase in wet inorganic nitrogen deposition in 2011 for the Eastern United States has resulted in smaller decreases in 3-year average comparisons for total nitrogen deposition for the 2009–2011 versus 2000–2002 time periods than would have been seen if the precipitation were typical for the year.

Figure 6: Precipitation from NADP/NTN and the PRISM model from 2010 and 2011



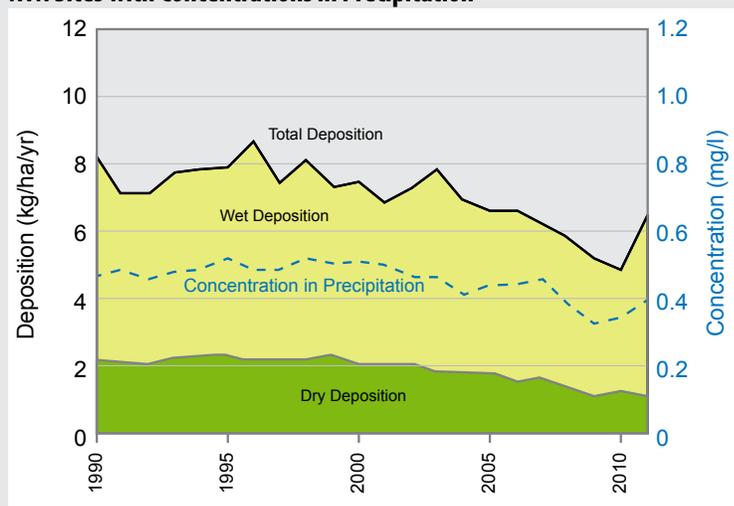
Source: EPA, 2013

Figure 7: Wet Inorganic Nitrogen Deposition in 2010 and 2011 from NADP/NTN and PRISM



Source: EPA, 2013

Figure 8: Trend in Nitrogen Deposition from Eastern CASTNET and NADP/NTN Sites with Concentrations in Precipitation



Source: EPA, 2013



Ozone

Ozone pollution forms when NO_x and volatile organic compounds (VOCs) react in the presence of sunlight. Major sources of NO_x and VOC emissions include motor vehicles, solvents, industrial facilities, and electric power plants.

Meteorology plays a significant role in ozone formation. Dry, hot, sunny days are most favorable for ozone production. In general, ozone concentrations increase during the daylight hours, peak in the afternoon when the temperature and sunlight intensity are highest, and drop in the evening. Because ground-level ozone concentrations are highest when sunlight is most intense, the warm summer months (May 1 to September 30) are known as the ozone season.

Ozone Impacts on Human Health

Exposure to ozone has been linked to a variety of health effects. At levels found in many urban areas, ozone can aggravate respiratory diseases such as asthma, emphysema, and bronchitis, and can increase susceptibility to respiratory infections. More serious effects include emergency department visits, hospital admissions, and premature mortality.

For more information on the health and environmental effects of ground-level ozone, visit EPA's Ground-level Ozone website at epa.gov/ozon-pollution.

NO_x Reduction Programs and Ozone

To better understand how the CAIR, NBP, and ARP NO_x programs affected ozone formation in the atmosphere, this report examines changes in ozone concentrations before and after implementation of the NBP and CAIR. The report compares regional and geographic trends in ozone levels to changes in NO_x emissions from CAIR sources.

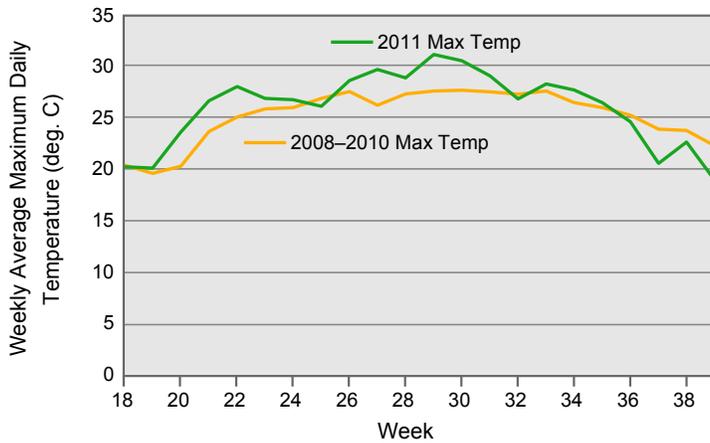
Ozone Standards

The CAA requires EPA to set National Ambient Air Quality Standards (NAAQS) for ground-level ozone and five other criteria pollutants. In the 1970s, EPA established the NAAQS for ozone. A 1-hour standard of 0.08 parts per million (ppm) was set in 1971 and revised to 0.12 ppm in 1979. In 1997, a new, more stringent 8-hour ozone standard of 0.08 ppm was promulgated, revising the 1979 standard. In March 2008, EPA changed the 8-hour ozone standard to 0.075 ppm. CAIR was promulgated to help downwind states in the eastern U.S. achieve the 1997 ozone NAAQS, and therefore analyses in this report focus on that standard.

Measuring and Evaluating Changes in Ozone

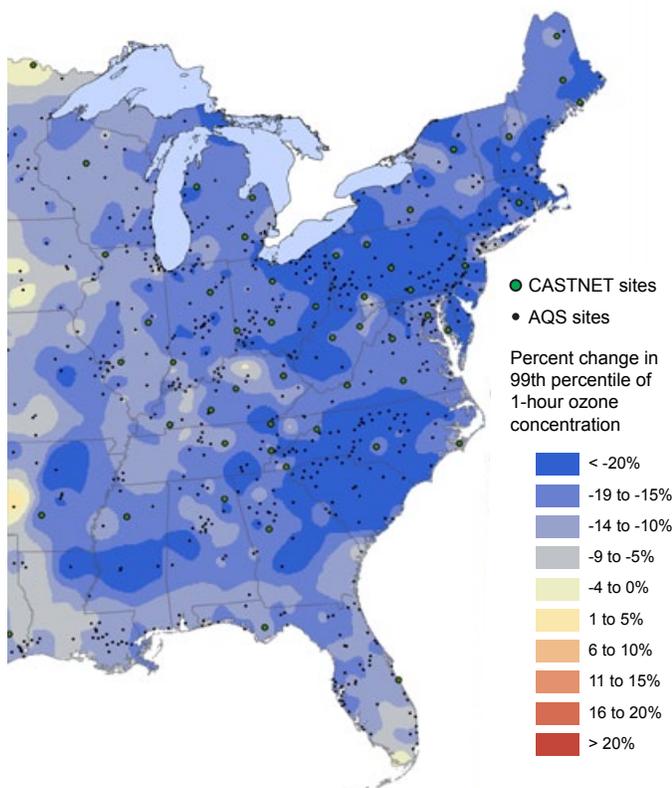
Two long-term monitoring networks, the State and Local Air Monitoring Stations (SLAMS) and CASTNET, measure ozone levels as well as meteorological and other air quality data throughout the United States. SLAMS monitoring sites used for regulatory compliance are located mainly in urban areas and report data to EPA's Air Quality System (AQS). CASTNET sites measure trends in ozone at rural sites and these data are also used for

Figure 9: Weekly Average of Maximum Ozone Season Daily Temperatures, 2008–2011



Source: EPA, 2013

Figure 10: Percent Change in 1-Hour Ozone Concentrations during the Ozone Season, 2000–2002 versus 2009–2011



Note: Data are from AQS and CASTNET monitoring sites with two or more years of data within each three-year monitoring period.

Source: EPA, 2013

regulatory compliance and reported to AQS. The changes in eastern ozone concentrations presented in this report depict data from AQS and CASTNET monitoring sites located within both CAIR and adjacent states. These analyses show a range of ozone reductions based on the metric used and the years examined.

Meteorological Effects on Environmental Trends

Detecting trends or causal effects in air quality requires several data points or multiple-year averages because of natural variability in environmental measurements and meteorology. Figure 9 shows the weekly average of maximum daily temperatures during the CAIR NO_x ozone season at CASTNET sites included in the CAIR region that met the data completeness criteria. During the ozone season months in 2011, the average of maximum daily temperatures were typically higher than the three year average in 2008–2010, making it important to account for meteorological effects when assessing any trends in air pollution after CAIR was implemented.

Changes in Rural Ozone Concentrations

Rural ozone measurements are useful in assessing the impacts on air quality resulting from regional NO_x emission reductions because these monitoring sites are typically less affected by local sources of NO_x (e.g., industrial, mobile, and power generation sources) than urban measurements. Consequently, the formation of ozone in these areas is particularly sensitive to changes in levels of regional NO_x emissions. The majority of reductions in rural ozone concentrations can therefore be attributed to reductions in regional NO_x emissions and transported ozone. EPA investigated trends in both rolling 8-hour and 1-hour ozone concentrations as measured at CASTNET monitoring sites within the CAIR NO_x ozone season region and in adjacent states (states within 200 km of a CAIR NO_x ozone season state's borders).

Changes in 1-Hour Ozone Concentrations in the East

EPA examined changes in unadjusted regional 1-hour ozone concentrations, as measured at urban (AQS) and rural (CASTNET) sites. Results demonstrate how NO_x emission reduction policies have affected ozone concentrations in the eastern United States. Figure 10 shows changes in the 99th percentile of 1-hour ozone concentrations

between 2000–2002 (before implementation of the NBP) and 2009–2011 (under the CAIR NO_x ozone season program). Using this metric, an overall regional reduction in ozone levels was observed between these two time periods, with an average reduction in ozone concentrations in CAIR states of 18 percent.

Regional Trends in Ozone

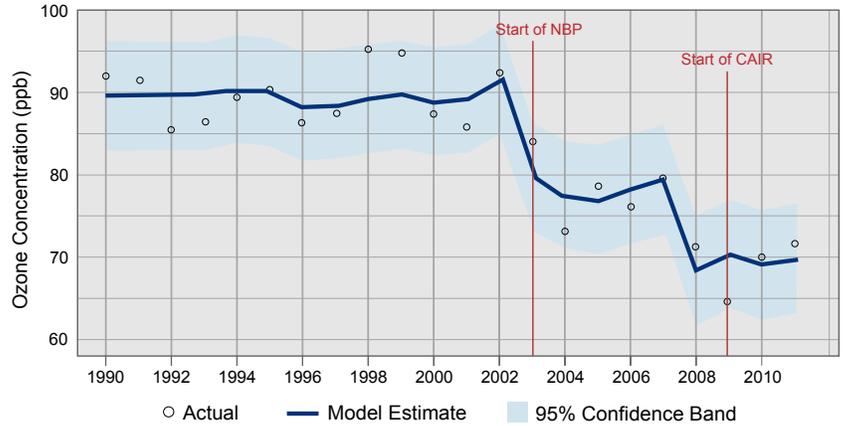
An Autoregressive Integrated Moving Average (ARIMA) model was used to determine the trend in ozone concentrations since the inception of various programs geared towards reducing NO_x emissions. The ARIMA model is an advanced statistical analysis tool that can evaluate trends over time (time series analysis). The average of the 99th percentile of the 8-hour daily maximum ozone concentrations (the highest daily levels of ozone) measured at CASTNET sites during the CAIR NO_x ozone season was modeled (Figure 11).

The ARIMA model shows a statistically significant, 13 percent (11 ppb) decrease in ozone concentrations beginning at the start of the NBP in 2003, followed by a 10 percent (8 ppb) reduction in ozone concentrations just prior to the start of CAIR in 2008, suggesting that these programs are a major contributor to regional improvements in ozone. In 2011, the third compliance year of the CAIR NO_x programs, ozone concentrations were slightly higher than the previous two years, likely due to the higher temperatures recorded in the Eastern United States. Ozone concentrations were down 20 ppb (21 percent) in 2011 versus 1990.

Changes in 8-Hour Ozone Concentrations

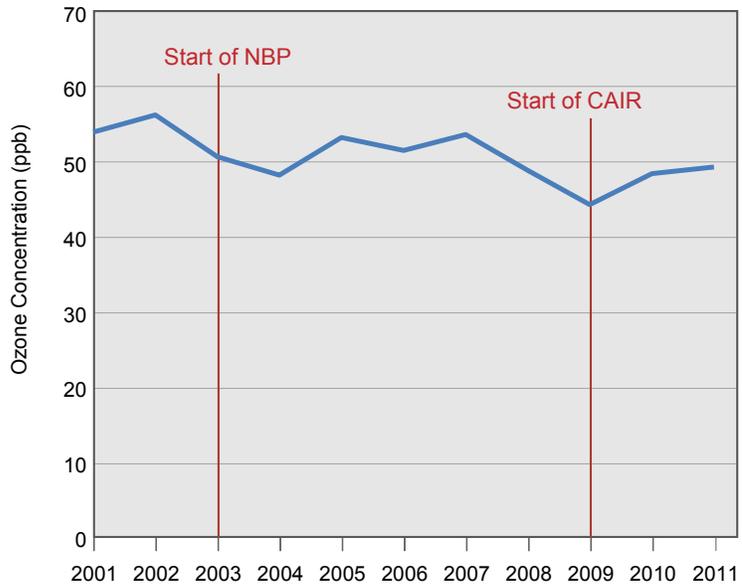
Daily maximum 8-hour ozone concentration data were assessed from 83 urban AQS areas and 40 rural CASTNET sites located in the CAIR NO_x ozone season program region. Figure 12 shows trends in the seasonal average daily maximum 8-hour ozone concentrations in the CAIR NO_x ozone season region unadjusted for the influence of weather.² The average reduction in seasonal daily maximum 8-hour ozone concentrations measured in the CAIR NO_x region in the 2001 to 2003 and 2009 to 2011 time periods was about 12 percent. However, as noted earlier, weather plays an important role in determining ozone levels. Meteorologically adjusted data, currently unavailable for 2011, would provide additional insight on the influence of CAIR NO_x ozone season program emission reductions on regional air quality.

Figure 11: Shift in 99th Percentile 8-Hour Seasonal Rural Ozone Concentrations in the CAIR NO_x Ozone Season Region, 1990–2011



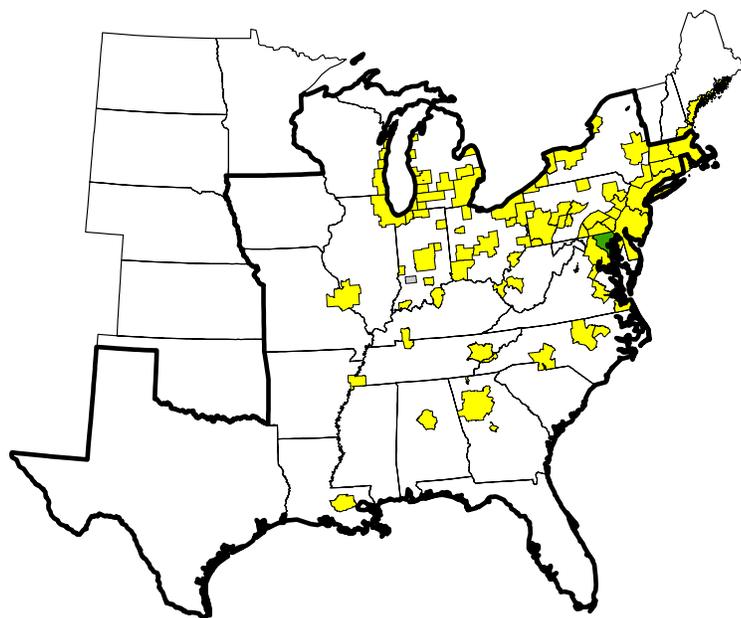
Note: Ozone concentration data are from CASTNET sites that met completeness criteria and are located in and adjacent to the CAIR NO_x region. Source: EPA, 2013

Figure 12: Seasonal Average of 8-hour Ozone Concentrations in CAIR States Unadjusted for Weather



Note: For a monitor or area to be included in this trend analysis, it had to provide complete and valid data for 50 percent of the ozone season days for each of the years from 2001 to 2011. In addition, urban AQS areas often include more than one monitoring site. In these cases, the site with the highest observed ozone concentration for each day was used. Source: EPA, 2013

Figure 13: Changes in Nonattainment Areas in the CAIR Region, 2001–2003 (Original Designations) versus 2009–2011



- Attained 1997 8-hour ozone NAAQS (89 areas)
- Above NAAQS, showing improvement (1 area)
- Incomplete data for 2009–2011 (1 area)

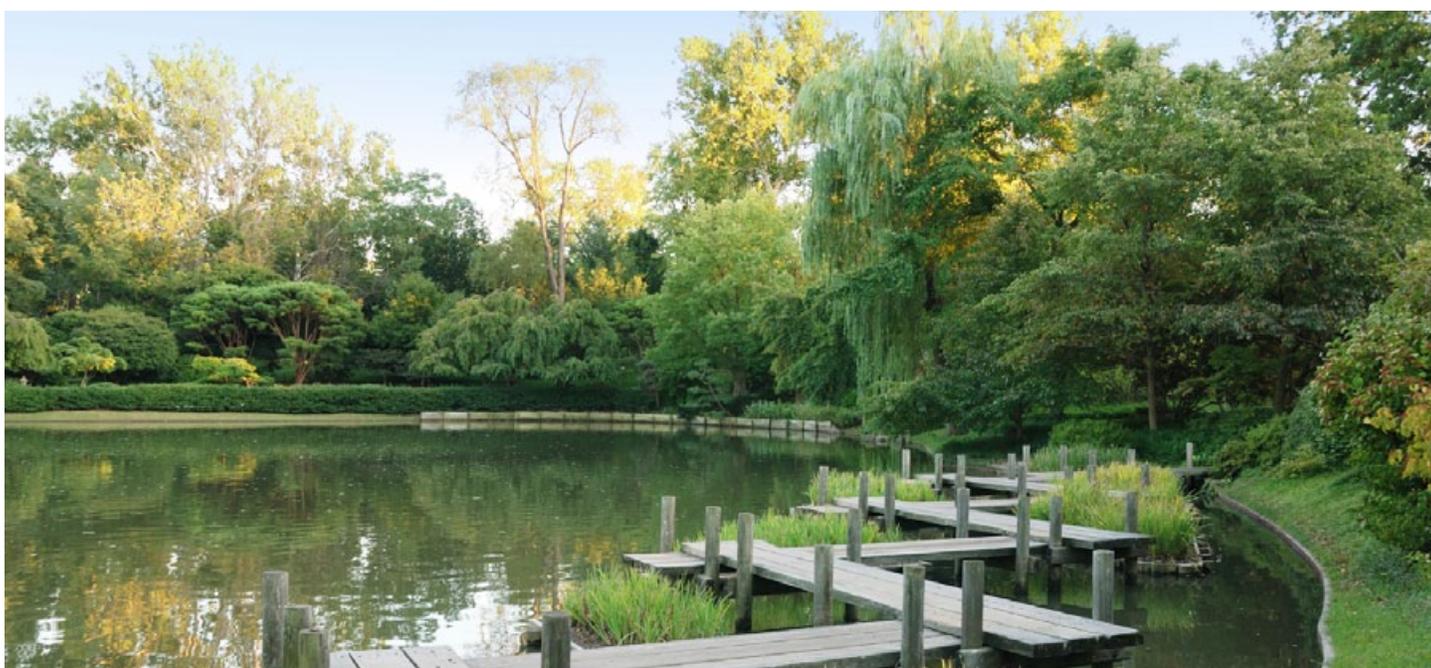
CAIR States controlled for PM and/or ozone are outlined.

Source: EPA, 2013

Changes in Ozone Nonattainment Areas

In April 2004, EPA designated 126 areas as nonattainment for the 8-hour ozone standard adopted in 1997, of which 113 designations took legal effect.³ These designations were made using data from 2001 to 2003. Of those areas, 91 are in the East (as shown in Figure 13) and are home to about 103 million people.⁴ Based on data gathered from 2009 to 2011, 90 of these original eastern nonattainment areas show concentrations below the level of the 1997 ozone standard (0.08 ppm), indicating improvements in ozone. Improvements in these 90 areas mean that over 98 percent of the original nonattainment areas in the East now have ozone air quality that is better than the standard under which they were originally designated nonattainment. The Baltimore, Maryland area is the only one of the original 91 areas in the East that continues to exceed the level of the standard. In this area, however, ozone concentrations have fallen by over 10 percent. Because of the reductions in all 91 areas, millions of Americans living in these areas are experiencing better air quality.

Given that the majority of power sector NO_x emission reductions occurring after 2003 are attributable to the NBP and CAIR, it is reasonable to conclude that these NO_x reduction programs have been a significant contributor to these improvements in ozone air quality.



Particulate Matter

“Particulate matter,” also known as particle pollution or PM, is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles. Fine particles (PM_{2.5}) can form when gases emitted from power plants, industrial sources, automobiles, and other sources react in the air.

Particulate Matter Impacts on Human Health

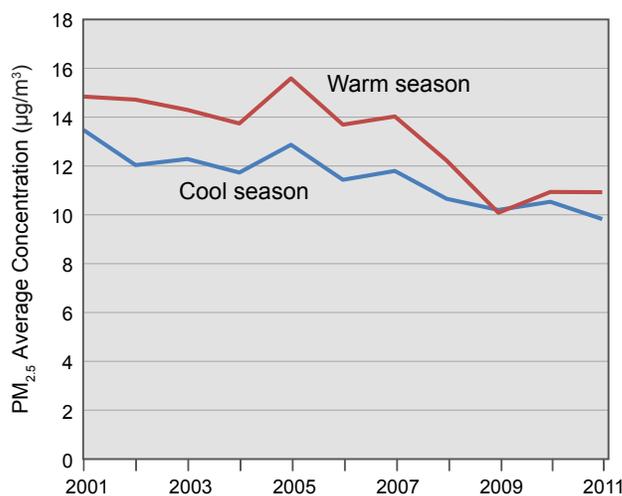
Particle pollution—especially fine particles—contains microscopic solids or liquid droplets that are so small that they can get deep into the lungs and cause serious health problems. Numerous scientific studies have linked particle pollution exposure to a variety of problems, including: increased respiratory symptoms, such as irritation of the airways, coughing, or difficulty breathing; decreased lung function; aggravated asthma; development of chronic bronchitis; irregular heartbeat; nonfatal heart attacks; and premature death in people with heart or lung disease.

For more information on the health and environmental effects of particulate matter, visit EPA’s Particulate Matter website at <epa.gov/air/particle-pollution>.

Particulate Matter Standards

The CAA requires EPA to set NAAQS for particle pollution. The first PM standard for fine particles was set by EPA in 1997 at 65 micrograms per cubic meter (µg/m³) measured as the three year average of the 98th percentile for 24-hour exposure, and at 15 µg/m³ for annual exposure measured as the three-year annual mean. EPA revised the air quality standards for particle pollution in 2006. The 2006 standards tightened the 24-hour fine particle standard to 35 µg/m³, and retained the annual fine particle standard at 15 µg/m³. Recently, in December 2012, EPA strengthened the annual fine particles standard to 12 µg/m³. CAIR was promulgated to help downwind states in the eastern U.S. achieve the 1997 annual average PM_{2.5} NAAQS, and therefore analyses in this report focus on that standard.

Figure 14: PM_{2.5} Seasonal Trends



Note: For a monitor or area to be included in this trend analysis, it had to provide complete and valid data for at least 60 days in each of the years from 2001 to 2011. In addition, urban AQS areas often include more than one monitoring site. In these cases, the site with the highest observed PM_{2.5} concentration for each day was used.

Source: EPA, 2013

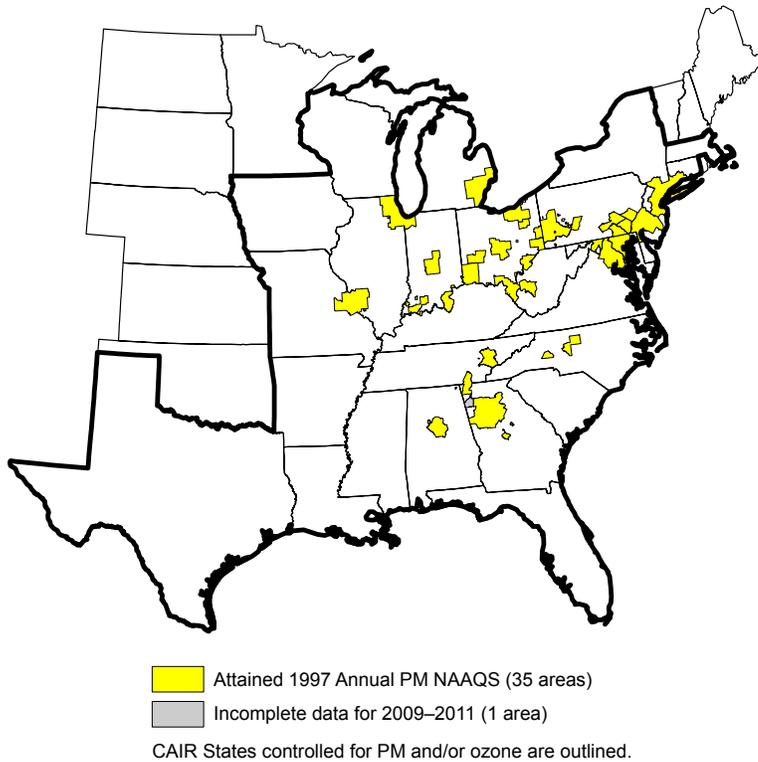
Annual Emission Reduction Programs and PM_{2.5}

The CAIR NO_x annual program and CAIR SO₂ program were established to address the interstate transport of PM_{2.5} pollution throughout the year and help eastern U.S. counties attain the PM_{2.5} annual standard. To better understand how emission reductions under CAIR and the ARP affected the formation of PM_{2.5}, this report presents regional and geographic trends in PM_{2.5} levels prior to implementation of any of the CAIR annual programs, and for 2011.

Trends in PM_{2.5} Concentrations

Average PM_{2.5} concentration data were assessed from 431 urban AQS areas located in the CAIR NO_x and SO₂ annual program region. Figure 14 shows separate trends in PM_{2.5} concentrations in the CAIR NO_x and SO₂ annual program region for the warm months (April to September) and cool months (October to March) unadjusted for the influence of weather.⁵ These separate graphs are shown due to the seasonal variability of the components that make up PM_{2.5}. The annual average PM_{2.5} concentration has decreased by about 26 percent in the warm season and about 27 percent in the cool season between 2001 and 2011. However, as noted earlier, weather plays an important role in the formation of PM. Meteorologically adjusted data, currently unavailable for

Figure 15: Changes in PM Nonattainment Areas in the CAIR Region, 2001–2003 (Original Designations) versus 2009–2011



Source: EPA, 2013

2011, would provide additional insight on the influence of annual CAIR SO₂ and NO_x program emission reductions on regional air quality.

Changes in PM_{2.5} Nonattainment Areas

In January 2005, EPA designated 39 areas as nonattainment for the 1997 annual average PM_{2.5} standard, one of which was also designated nonattainment for the 24-hour average PM_{2.5} standard.⁶ These designations were made using data from 2001 to 2003. Of those areas, 36 are in the East (as shown in Figure 15) and are home to about 88 million people.⁷ Based on data gathered from 2009 to 2011, 35 of these original eastern areas show concentrations below the level of the 1997 PM_{2.5} standard (15.0 µg/m³), indicating improvements in PM_{2.5} air quality. Improvements in these 35 areas mean that 97 percent of the areas originally designated nonattainment in the East

now have PM_{2.5} air quality that is better than the standard under which they were originally designated nonattainment.

The Floyd County (Georgia) area does not have sufficient PM_{2.5} data to quantify its change in air quality relative to the standard.

Given that the majority of power sector NO_x and SO₂ emission reductions occurring after 2003 are attributable to the ARP, NBP, and CAIR, it is reasonable to conclude that these emission reduction programs have been a significant contributor to these improvements in PM_{2.5} air quality.

Health Benefits of the ARP, NBP, and CAIR

By reducing precursors (SO₂ and NO_x) to PM_{2.5} formation and a precursor (NO_x) to ground-level ozone formation, emission reductions achieved by the ARP, NBP, and CAIR significantly benefit human health and welfare.^{8,9,10} Exposure to PM_{2.5} and ozone is linked to premature death as well as a variety of non-fatal effects including heart attacks, hospital and emergency department visits for respiratory and cardiovascular symptoms, acute bronchitis, aggravated asthma, and days when people miss work or school.^{11,12}

Ecosystems

Acid deposition (i.e., acid rain) resulting from SO₂ and NO_x emissions negatively affects the health of lakes and streams in the United States. The 2011 National Acid Precipitation Assessment Program (NAPAP) Report to Congress noted that the ARP has been successful in reducing emissions of SO₂ and NO_x from power generation and acid deposition has decreased to the extent that some acid-sensitive lakes and streams are beginning to recover from acidification. However, the report also states that current emission-reduction levels are not sufficient to allow full recovery of acid-sensitive ecosystems.¹³

Improvements in Surface Water Chemistry

Surface water chemistry provides direct indications of the potential effects of acidic deposition on the overall health of aquatic ecosystems. In collaboration with other federal and state agencies and universities, EPA administers two monitoring programs that provide information on the impacts of acidic deposition on otherwise protected aquatic systems: the Temporally Integrated Monitoring of Ecosystems (TIME) and the Long-term Monitoring (LTM) programs. These programs are designed to track changes in surface water chemistry in the four acid sensitive regions shown in Figure 16: New England, the Adirondack Mountains, the Northern Appalachian Plateau, and the central Appalachians (the Valley and Ridge and Blue Ridge Provinces).

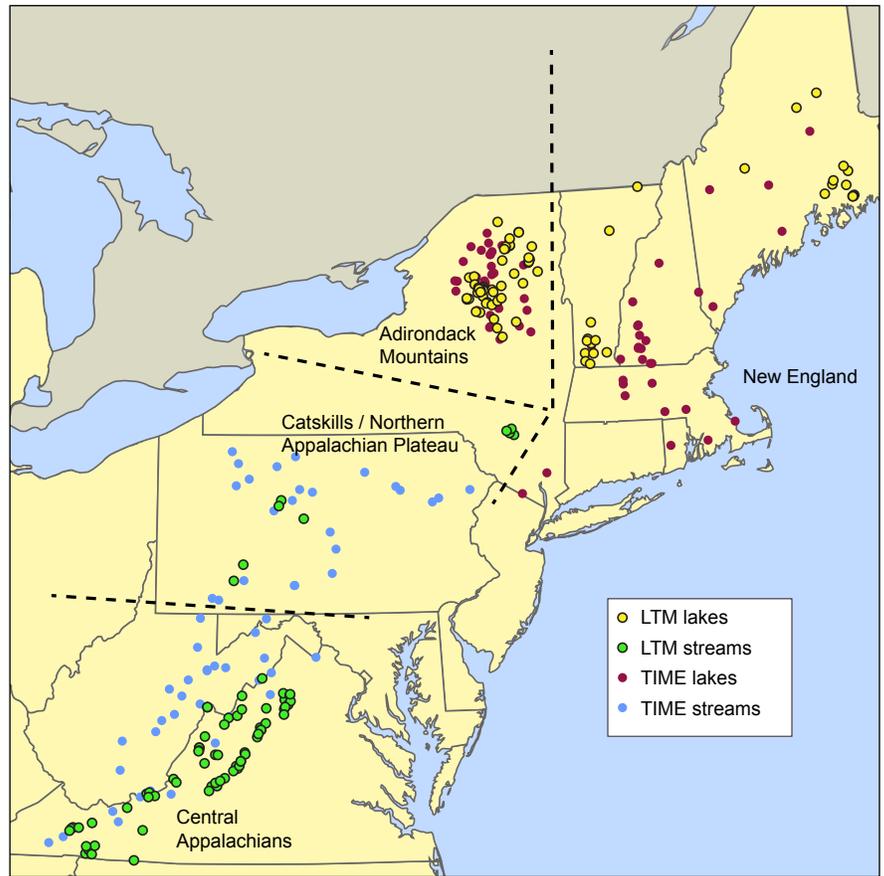
Table 2 on page 16 shows regional trends in acidification from 1990 (before implementation of the ARP) to 2011 in lakes and streams throughout the LTM program. Five indicators of aquatic ecosystem response to emission changes are presented: measured ions of sulfate, nitrate, neutral salt base cations (sum of calcium, magnesium, and potassium ions), acid neutralizing capacity (ANC), and dissolved organic carbon (DOC). These indicators provide information regarding the surface water sensitivity to acidification. Trends in these measured chemical receptors allow for the determination of whether the conditions of the water bodies are improving and heading towards recovery or if the conditions are still acidifying. The following is a description of each indicator represented in Table 2:

Sulfate is the primary negatively charged ion in most acid-sensitive waters and has the potential to acidify drainage waters and leach aluminum and base cations from the soils.

Nitrate has the same potential as sulfate to acidify drainage waters. However, nitrogen is a limiting nutrient for plant growth and a large portion of nitrogen inputs from deposition are quickly incorporated into plants as organic nitrogen, leaving less leaching of nitrate into surface waters.

Base cations are the positively charged ions in surface waters that buffer both sulfate and nitrate

Figure 16: Long Term Monitoring Program Sites



Source: EPA, 2013

ions, thereby preventing surface water acidification. ANC is a measure of acidification, which results in the diminishing ability of surface waters to neutralize strong acids that enter aquatic systems. When ANC is low, and especially when it is negative, stream water pH is also low (less than pH 6), and there may be adverse impacts on fish and other animals essential for a healthy aquatic ecosystem. Water bodies with ANC values less than or equal to 0 microequivalents per liter ($\mu\text{eq/L}$) are defined as being of acute concern for acidification. Lakes and streams having springtime ANC values less than 50 $\mu\text{eq/L}$ are generally considered of elevated concern for acidification. Lakes and streams with ANC higher than 50 $\mu\text{eq/L}$ are generally considered of moderate to low concern for acidification. Movement toward recovery of an aquatic ecosystem is indicated by increasing trends in ANC and decreasing trends in sulfate and nitrate concentrations.

Dissolved organic carbon (DOC) is essentially organic material that is an important part of the acid-base chemistry of most low-ANC freshwater systems. While a host of factors control DOC dynamics in surface waters, increased concentrations of DOC can be indicative of reduced acidification from acid deposition and/or a sign of increased decomposition of organic matter in the watershed.

As seen in Table 2, significant improving trends in sulfate concentrations from 1990 to 2011 are found at nearly all monitoring sites in New England, Adirondacks, and the Catskill mountains/Northern Appalachian Plateau. However, in the Central Appalachians only 15 percent of monitored streams showed a decreasing sulfate trend, while sulfate concentrations in 12 percent of monitored streams actually increased. The highly weathered soils of the Central Appalachians are able to store large amounts of deposited sulfate, but as long-term sulfate deposition exhausts the soil's ability to store more sulfate, a decreasing proportion of the deposited sulfate is retained in the soil and an increasing proportion is exported to surface waters. Thus sulfate concentrations in surface waters, mainly streams in this region, are increasing despite reduced sulfate deposition.

Nitrate concentration trends are decreasing at some of the sites in all four regions, but some sites also indicate flat or slightly increasing nitrate trends. Improving trends for nitrate concentration were noted at 38 percent of all monitored sites, but this improvement may only be partially explained by decreasing deposition. Ecosystem factors, such as vegetation disturbances, increased uptake by vegetation, and soil retention are also known to contribute to declining surface water nitrate concentrations.

Improving ANC trends are likely the result of reductions in sulfate deposition levels. From 1990 to 2011, monitoring sites in the Adirondacks (68 percent), and the Catskills/northern Appalachian Plateau (45 percent) showed the strongest improvement in ANC trends while sites in New England (32 percent) and the Central Appalachians (36 percent) had fewer sites with improving ANC trends. In New England, hydrology and declining trends of base cation concentrations may delay the onset of recovery. Decreasing base cation levels can balance out reductions of sulfate and nitrate, thereby preventing ANC from increasing. DOC is increasing at 42 percent of all monitored lakes and streams.¹⁴ This is likely linked to declines in sulfate concentrations as well as warmer seasonal and annual temperatures.

Table 2: Regional Trends in Sulfate, Nitrate, ANC, Neutral Salt Base Cations (Calcium, Magnesium, Potassium), and DOC at Long-term Monitoring Sites, 1990–2011

Region	Water Bodies Covered	% of Sites with Improving Sulfate Trend	% of Sites with Improving Nitrate Trend	% of Sites with Improving ANC Trend	% of Sites with Improving Base Cations*	% of Sites with Improving DOC Trend (Subset of Sites Analyzed)
Adirondack Mountains	50 lakes in NY	100%	56%	68%	88%	48% (29 sites)
Catskills/N. Appalachian Plateau	9 streams in NY and PA	80%	40%	45%	90%	38% (9 sites)
New England	26 lakes in ME and VT	100%	18%	32%	71%	32% (13 sites)
Central Appalachians	66 streams in VA	15%	59%	36%	18%	NA

*Assume neutral salt for these calculations.

Notes:

- Trends are determined by multivariate Mann-Kendall tests.
- Trends are significant at the 95 percent confidence interval ($p < 0.05$).
- DOC was only examined in low-ANC waterbodies (ANC less than 25 $\mu\text{eq/L}$).
- DOC is not currently measured in Central Appalachian streams.

Source: EPA, 2013

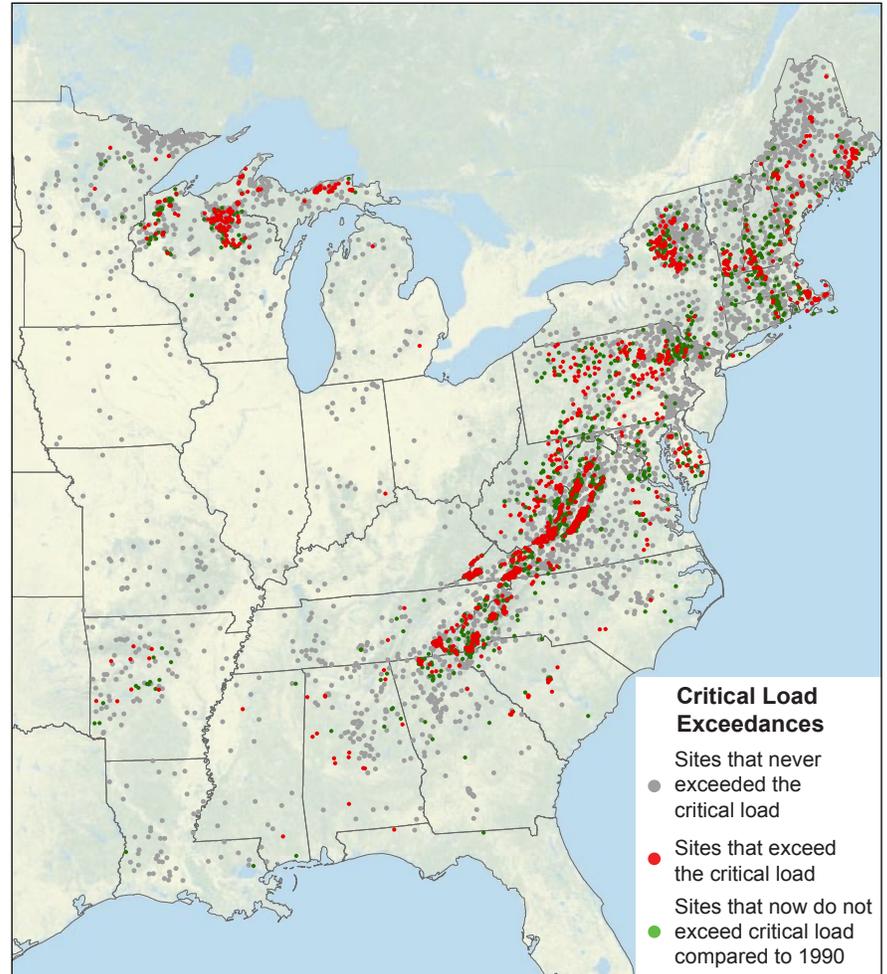
Critical Loads and Exceedances

The critical load approach is an assessment tool that can be used to assess the degree to which air pollution may be affecting the health of aquatic systems. A critical load is a quantitative estimate of exposure to one or more pollutants below which significant harmful effects on specific sensitive elements of the environment do not occur according to present knowledge.¹⁵ This approach provides a useful lens through which to help understand the potential aquatic ecological benefits that have resulted from emission reduction programs such as the ARP and CAIR.

Using methods from the peer-reviewed scientific literature,^{16,17} critical loads were calculated for over 6,400 lakes and streams using the Steady-State Water Chemistry (SSWC) model. This analysis represents lakes and streams where surface water samples have been collected through programs such as National Surface Water Survey (NSWS), Environmental Monitoring and Assessment Program (EMAP), Wadeable Stream Assessment (WSA), National Lake Assessment (NLA), the TIME program, the LTM program, and other water quality programs. The lakes and streams associated with these programs consist of a subset of lakes and streams located in areas affected by acid deposition, but are not intended to represent all water bodies in the eastern half of the US.

For this particular analysis, the critical load represents the combined deposition loads of sulfur and nitrogen to which a lake or stream could be subjected and still be healthy enough to protect most fish and other aquatic organisms. Critical loads of combined total sulfur and nitrogen deposition are expressed in terms of ionic charge balance as milliequivalents per square meter per year ($\text{meq}/\text{m}^2/\text{yr}$). If a water body is exposed to pollutant levels, in this case deposition levels, below its estimated critical load, then adverse ecological effects (e.g., reduced reproductive success, stunted growth, loss of biological diversity) are not anticipated, and recovery from damage due to past exposure is expected over time. If a water body is exposed to pollutant levels that are higher than, or exceed, its estimated critical load, then damaging ecological effects are anticipated to continue.

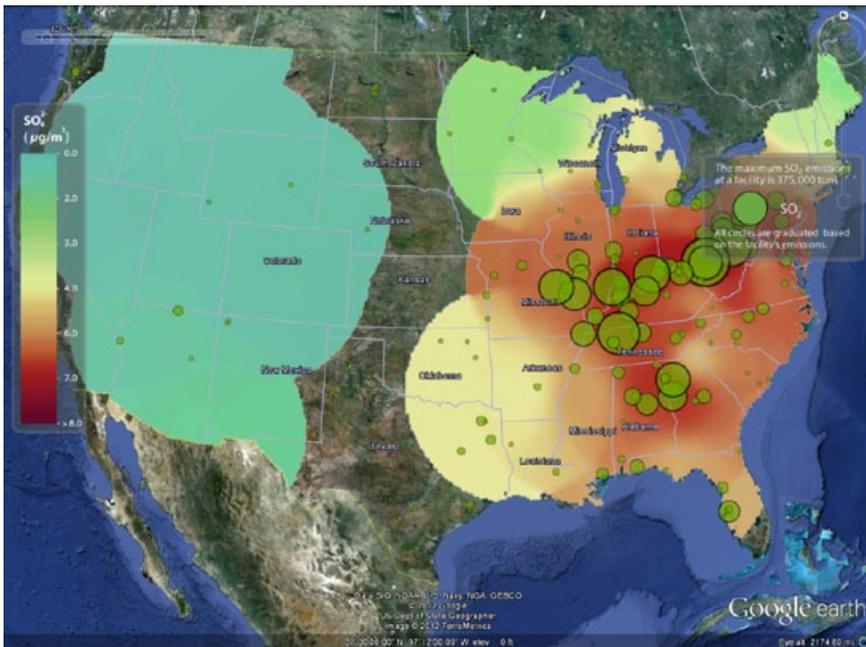
Figure 17: Lake and Stream Exceedances of Estimated Critical Loads for Total Nitrogen and Sulfur Deposition for the Period between 1989–1991 and 2009–2011



Source: EPA, 2013

To assess the extent to which regional lake and stream ecosystems are protected by the emission reductions achieved by the ARP, CAIR, and other regional and state programs so far, this analysis compares the amount of deposition systems can receive—the critical load—to measured deposition for the period before implementation of the ARP (1989 to 1991) and for a recent period after ARP and CAIR implementation (2008 to 2011). Overall, emission reductions achieved since 1990 have contributed significantly to improved environmental conditions and increased ecosystem protection in the eastern half of the US. The per-

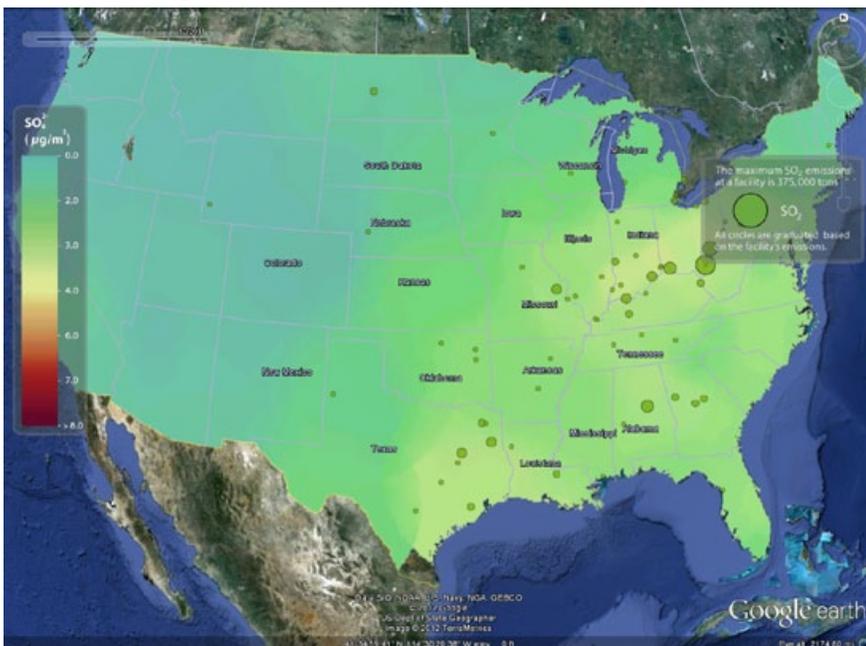
Figure 18: US SO₂ Emissions and Sulfate Concentrations, 1990



Note: This example depicts 1990 SO₂ emissions from ARP, NBP, and CAIR sources along with 1990 annual mean ambient particulate sulfate concentration data as measured by the CASTNET monitoring program.

Source: EPA, 2013

Figure 19: US SO₂ Emissions and Sulfate Concentrations, 2011



Note: This example depicts 2011 SO₂ emissions from ARP, NBP, and CAIR sources along with 2011 annual mean ambient particulate sulfate concentration data as measured by the CASTNET monitoring program.

Source: EPA, 2013

cent of the water bodies examined receiving levels of combined sulfur and nitrogen deposition that exceed the critical load (i.e., are considered to be harmful to the aquatic system) decreased from 42 percent in the 1989–1991 observation period to 23 percent in the 2009–2011 observation period (Figure 17 on page 17).

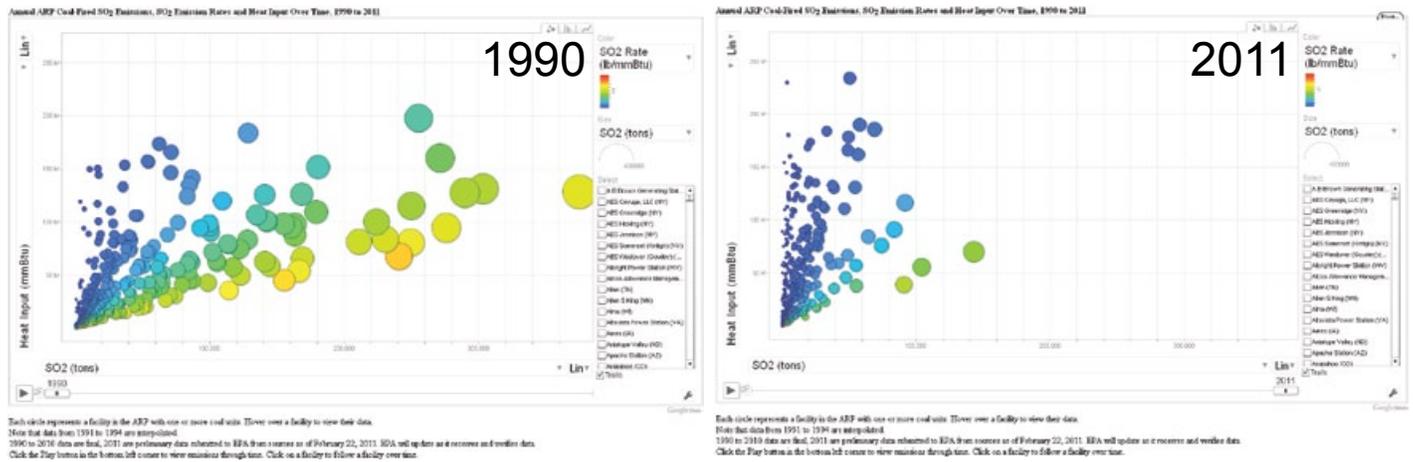
While all acid-sensitive regions saw much improvement, many areas still have numerous affected lakes and streams. The largest concentration of water bodies where acid deposition currently is greater than—or exceeds—estimated critical loads include the southern Adirondack mountain region in New York, southern New Hampshire, Cape Cod Massachusetts, and along the Appalachian Mountain spine from Pennsylvania to North Carolina. The upper Midwest also contains lakes that receive acidic deposition above their critical loads, but many may be naturally acidic and not responsive to changes in acidic deposition. While the monitoring coverage of lakes and streams in the Midwest is much less than the eastern US, this analysis shows that those water bodies are largely protected from acidic deposition despite relatively high levels of deposition in this region (see Figures 4 and 5 on pages 6 and 7). The exception is in Missouri where some water bodies remain sensitive to acid deposition.

Online Resources

The availability and transparency of data, from emission measurement to allowance trading to deposition monitoring, is a cornerstone of effective emission reduction programs. EPA develops and manages programs for collecting these data and assessing the effectiveness of emission reduction programs, including the ARP, NBP, and CAIR. These data are then made available to the public in readily usable and interactive formats.

To increase data transparency, EPA has created supplementary maps that allow the user to display ARP and CAIR program data geospatially on an interactive 3D platform. Figure 18 and Figure 19 are examples of these maps. The maps come in the form of a KMZ file (a compressed KML file) that is downloaded directly to the user's computer. Data can be explored in new and meaningful ways by turning different layers on and off, overlaying data points and satellite imagery, and using navigation tools to change the view of the Earth's surface. KMZ/KML files are supported by programs

Figure 20: Motion Charts of Annual ARP Coal-Fired Emissions, SO₂ Emission Rates and Heat Input over Time, 1990 and 2011



Source: EPA, 2013

such as Google Earth, ESRI Arc Explorer, and NASA WorldWind View. These interactive mapping applications provide a unique way to identify environmental trends and track the progress of various EPA programs. For more information or to utilize this tool, visit the Interactive Mapping website at <epa.gov/airmarkets/progress/interactive-mapping.html>.

In another effort to increase data transparency, EPA regularly posts updates of quarterly SO₂ and NO_x emissions data from coal-fired power plants controlled under the ARP and CAIR programs to make it easy for the public to track changes in emissions from these sources (available at the Emissions Tracking website at <epa.gov/airmarkets/quarterlytracking.html>). The data presented on

this website compare emissions, emission rates, and heat input from these power plants. These files graphically and spatially compare quarterly emission data from the most recent completed quarter with data for the same quarter in the preceding year.

Interactive motion charts are a key feature on the emissions tracking website. Figure 20 shows examples of motion charts created to show changes in ARP and CAIR SO₂ emissions and SO₂ emission rates over time (from 1990 to 2011). These motion charts show, historically, how coal-fired power plants have responded to the ARP and CAIR. On the emissions tracking website, the user can watch this data move through time by clicking the play button.

Notes

1. EME Homer City Generation, L.P. v. EPA, 696 F.3d 7, 37-38 (D.C. Cir. 2012).
2. Met-adjusted ozone data are not available for 2011.
3. 40 CFR Part 81. Designation of Areas for Air Quality Planning Purpose
4. U.S. Census. 2000.
5. Met-adjusted PM_{2.5} data are not available for 2011.
6. 40 CFR Part 81. Designation of Areas for Air Quality Planning Purposes.
7. U.S. Census. 2000.
8. U.S. Environmental Protection Agency (U.S. EPA). 2009. Acid Rain and Related Programs: 2008 Emission, Compliance, and Market Analyses Progress Report. September. Available on the Internet at http://www.epa.gov/airmarkets/progress/ARP_2008_ECM_Analyses.pdf
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10. U.S. Environmental Protection Agency (U.S. EPA). 2011. EPA's NO_x Reduction Program and Clean Air Interstate Rule 2009 Environmental and Health Results Progress Report. January. Available on the Internet at http://www.epa.gov/airmarkets/progress/CAIR_09/CAIR_downloads/CAIR09_Environmental_Results.pdf
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13. Burns, D.A., Lynch, J.A., Cosby, B.J., Fenn, M.E., Baron, J.S., US EPA Clean Air Markets Div., 2011, National Acid Precipitation Assessment Program Report to Congress 2011: An Integrated Assessment, National Science and Technology Council, Washington, DC, 114 p. Available on the Internet at ny.water.usgs.gov/projects/NAPAP/NAPAP_2011_Report_508_Compliant.pdf.
14. DOC was only examined in a subset LTM sites that exhibited low ANC (ANC less than 25 µeq/L). Also, DOC is not currently measured in Central Appalachian streams.
15. Nilsson, J. & Grennfelt, P. (Eds) (1988) Critical loads for sulphur and nitrogen. UNECE/Nordic Council workshop report, Skokloster, Sweden. March 1988. Nordic Council of Ministers: Copenhagen.
16. EPA, 2008 and DuPont J., T.A. Clair, C. Gagnon, D.S. Jeffries, J.S. Kahl, and S.J. Nelson, and J. M. Peckenham. (2005). Environmental Monitoring and Assessment 109: 275–291
17. Sullivan T.J., B.J. Cosby, J.R. Webb, R.L. Dennis, A.J. Bulger, and F.A. Deviney, Jr. 2007. Stream-water acid-base chemistry and critical loads of atmospheric sulfur deposition in Shenandoah National Park, Virginia. Environmental Monitoring and Assessment 137:85–99