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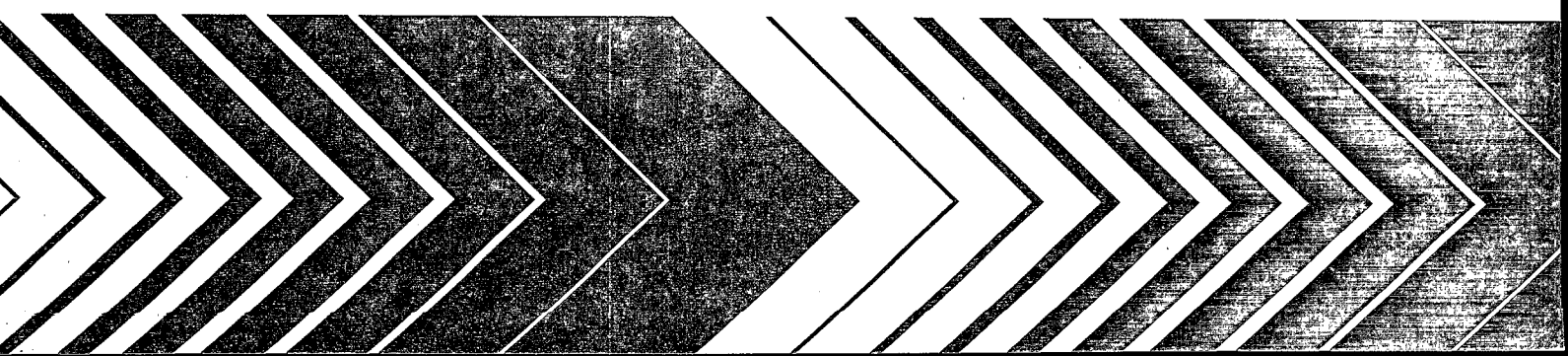
Clean Air Status and Trends Network (CASTNet) Deposition Summary Report (1987–1995)



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Clean Air Status and Trends Network (CASTNet) Deposition Summary Report (1987-1995)

by

QST Environmental Inc.
Gainesville, FL 32607

Contract No. 68-D2-0134

Project Officer

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Contents

Foreword

In 1986, the U.S. Environmental Protection Agency (EPA) established the National Dry Deposition Network (NDDN) as a part of the Agency's support to the National Acid Precipitation Assessment Program (NAPAP). The goal of the NDDN was to provide NAPAP with estimates of dry deposition flux to use in model evaluation, determination of spatial patterns of dry deposition, and to relate deposition to ecological effects. NAPAP was completed in 1990 with the issuance of the Integrated Assessment.

Also, in 1990, Congress amended the Clean Air Act. These amendments require reduction in emissions of sulfur and nitrogen oxides. A national monitoring network was mandated as part of the Clean Air Act Amendments to determine the effectiveness of these future emission reductions. EPA established the Clean Air Status and Trends Network (CASTNet) to provide data to determine relationships among emissions, air quality, deposition, and ecological effects. The basic tenets of CASTNet are to define the spatial distribution of pollutants, to detect and quantify trends in pollutants, to implement monitoring in cooperation with other agencies and organizations, and to implement monitoring to fill gaps in monitoring coverage.

In 1990, the NDDN became part of CASTNet. CASTNet is the primary source for atmospheric data to estimate dry deposition and to provide data on rural ozone. The National Atmospheric Deposition Program (NADP) is the primary source for data on wet deposition. CASTNet supplements the NADP with wet deposition measurements at selected sites. The National Oceanic and Atmospheric Administration provides intensive dry and wet deposition monitoring as part of the Atmospheric and Integrated Research Monitoring Network (AIRMoN). The National Park Service operates an air quality monitoring network for ozone, sulfur dioxide, and particulate matter at a number of National Parks. Each of the above networks contributes specific data to provide a comprehensive picture of deposition and air quality in primarily rural areas of the United States.

This report is a summary of the NDDN and CASTNet monitoring activities and the resulting concentration and deposition data from 1987 through 1995.

Acknowlegments

The success of the Clean Air Status and Trends Network (CASTNet) may best be measured by the quality and completeness of the data gathered. Data from a 50-site network, which consistently met or most often exceeded acceptance criteria and recorded completeness levels of greater than 90 percent, are the result of considerable dedication by a large number of individuals. Employees of QST Environmental Inc., site operators, and individuals of other contributing organizations are to be commended for their diligence and commitment to the goals of CASTNet.

Abstract

The National Dry Deposition Network (NDDN) was established in 1986 to provide long-term estimates of dry acidic deposition across the continental United States. In 1990, NDDN was incorporated into the Clean Air Status and Trends Network (CASTNet), which was created to address the requirements of the Clean Air Act Amendments (CAAA). Approximately 50 routine sites were operational from 1990 through 1995 with the majority of the sites located in the eastern United States. Each site is equipped with sensors for continuous measurements of ozone and meteorological variables required for estimation of dry deposition rates. Weekly average atmospheric concentrations of particulate sulfate (SO_4^{2-}), particulate nitrate (NO_3^-), particulate ammonium (NH_4^+), sulfur dioxide (SO_2), and nitric acid (HNO_3) were measured at all sites; and wet deposition of acidity and related species were measured at selected sites. Under CASTNet, a visibility monitoring network and a Mountain Acid Deposition Program (MADPro) were established. A micrometeorological model has been applied to calculate deposition velocities and estimate dry deposition fluxes.

Atmospheric concentration data showed species-dependent variability in space and time. In general, the highest concentrations were observed along the Ohio River valley, and these were a factor of 5 to 10 times higher than concentrations observed in the west. Significant concentration gradients were also observed from the northeast through upper northeast and midwest through upper midwest. Annual average concentrations of sulfur species decreased significantly from 1987 to 1995 in all subregions (defined in the report) of the network. Annual average concentrations of nitrogen species showed little change over the same time period.

Calculated dry deposition fluxes for 1987 through 1995 showed that SO_2 and HNO_3 dominate sulfur and nitrogen fluxes, respectively. In general, SO_2 accounts for about 70 percent of dry sulfur deposition at eastern sites and more than 55 percent of dry sulfur deposition at western sites. HNO_3 accounts for approximately 65 percent of dry nitrogen deposition at all sites. The highest sulfur depositions were measured in the northeast and midwest subregions. Data for all eastern sites showed a 29-percent reduction in SO_2 deposition and a 6-percent reduction in SO_4^{2-} deposition from 1989 through 1995. There is no apparent trend for western sites. The dry deposition calculations represent lower bound estimates of actual fluxes as model uncertainties have not been quantified.

Annual precipitation concentrations of SO_4^{2-} from 1989 to 1995 declined significantly in the upper northeast and southern periphery subregions. The eastern region exhibited a downward trend that was not statistically significant. There were no statistically significant trends in precipitation concentrations of NO_3^-.

Wet deposition measurements for 1989 through 1995 showed statistically significant reductions of sulfur species for all eastern sites combined, and for the upper northeast, northeast, midwest, and south-central subregions. Although no statistically significant reductions were observed for nitrogen species, the east and west regions and the upper northeast subregion exhibited downward trends.

Total (wet plus dry) deposition estimates for 1989 through 1995 showed that dry deposition accounts for about 15 to 45 percent of total sulfur deposition, and 20 to 60 percent of total nitrogen deposition. These data also showed that dry deposition is a more significant contributor in and near major source regions, and wet deposition is more significant in areas with heavy precipitation, such as the deep south and mountainous regions.

Analysis of ozone data collected throughout the network indicated considerable geographic variability in annual and short-term averages, but little year-to-year variability at individual stations. There was no discernible trend in annual averages. Hourly concentrations above the 1-hour NAAQS were limited to sites in the Washington-New York corridor. Concentrations above the proposed 8-hour standard were measured throughout the midwest and northeast subregions.

Data from MADPro for 1994 to 1996 showed that cloudwater can be the primary pathway for deposition of pollutants to high elevation ecosystems.

An initial analysis of visual air quality measurements taken in 1994 shows a strong relationship among atmospheric light scattering, fine particle concentrations, and visual quality. Fine particle concentrations peaked in the summer and were highly correlated with fine sulfate.

Tables

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Abbreviations and Symbols

ADS	annular denuder system
AIRMoN	Atmospheric and Integrated Research Monitoring Network
APD	absolute percent difference
APIOS	Acid Precipitation in Ontario Study
ATI	Applied Technology Incorporated
B_{scat}	atmospheric light scattering coefficient
°C	degrees Celsius
Ca^{2+}	calcium ion
CAA	Clean Air Act
CAAA	Clean Air Act Amendments
CAPMoN	Canadian Acid Deposition Monitoring Network
CASTNet	Clean Air Status and Trends Network
CDN	CASTNet Deposition Network
CDRF	Continuous Data Review Form
Cl^-	chloride ion
CLASS™	Chemistry Laboratory Analysis and Scheduling System
cm/sec	centimeters per second
CVS	continuing verification samples
%D	percent difference
DAS	data acquisition system
DBMS	database management system
DMC	Data Management Center
DRI	Desert Research Institute
EFPVN	Eastern Fine Particle and Visibility Network
EPA	U.S. Environmental Protection Agency
ESE	Environmental Science & Engineering, Inc.
°F	degrees Fahrenheit
g/m^3	gram per cubic meter
H^+	hydrogen ion
HNO_3	nitric acid
Hz	hertz
IC	ion chromatography
ICAP	inductively coupled argon plasma
IMPROVE	Interagency Monitoring of Protected Visual Environments
K^+	potassium ion
K_2CO_3	potassium carbonate
kg/ha	kilograms per hectare
km	kilometer
L	liter
LAI	leaf area index
LAN	Local Area Network
LIPM	light induced proton microscopy
Lpm	liters per minute
m	meter
MADPro	Mountain Acid Deposition Program
MCCP	Mountain Cloud Chemistry Project
MFC	mass flow controller
mg/L	milligrams per liter
Mg^{2+}	magnesium ion

Abbreviations and Symbols
(Continued)

MLM	Multilayer model
mmHg	millimeters of mercury
m/sec	meters per second
Na^+	sodium ion
NAAQS	National Ambient Air Quality Standard
NADP	National Atmospheric Deposition Program
NAPAP	National Acid Precipitation Assessment Program
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NDDN	National Dry Deposition Network
NH_4^+	particulate ammonium
NH_3	ammonia
NIST	National Institute of Standards and Technology
NO_2^-	particulate nitrite
NO_3^-	particulate nitrate
NOAA	National Oceanic and Atmospheric Administration
NO	nitric oxide
NO_x	nitrogen oxides
NP	National Park
NPS	National Park Service
NTN	National Trends Network
O_3	ozone
Ogden	Ogden Environmental and Energy Services, Inc.
PIXE	proton induced X-ray emission
ppb	parts per billion
ppm	parts per million
ppm-hr	parts per million hours
PSRF	Precipitation Sample Report Form
PVM	particle volume monitor
QA	quality assurance
QST	QST Environmental Inc.
RADM	Regional Acid Deposition Model
RAM	random-access memory
RPD	relative percent difference
SCION	Southern Consortium Intermediate Oxidant Network
SO_4^{2-}	particulate sulfate
SO_2	sulfur dioxide
SOP	standard operating procedure
SO_x	sulfur oxides
SSRF	Site Status Report Form
SURE	Sulfate Regional Experiment
TOR	Thermal Optical Reflectance
tpy	tons per year
UCD	University of California at Davis
USGS	U.S. Geological Survey
μg	microgram
$\mu g/m^3$	micrograms per cubic meter
μm	micrometer
UV	ultraviolet
V_d	deposition velocity

Executive Summary

The National Dry Deposition Network (NDDN) was established in 1986 to measure concentrations of gaseous and particulate air pollutants and meteorological parameters. The goal of NDDN was to use the air quality and meteorological measurements in combination with land use and vegetation data to estimate dry deposition throughout the continental United States. Field measurements began in 1987, and the network grew to 50 sites by 1990.

Congress amended the Clean Air Act (CAA) in 1990, calling for significant reductions in emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x). The 1990 CAA Amendments mandated a national air quality monitoring network to measure changes in air quality associated with the scheduled emission reductions. Consequently, the U.S. Environmental Protection Agency (EPA) created the Clean Air Status and Trends Network (CASTNet). CASTNet became operational in mid-1991, and NDDN was incorporated into CASTNet at that time.

Approximately 50 dry deposition sites were operational through 1995. From six to nine sites were operated at remote western sites; the remaining stations were operated at rural sites throughout the eastern United States. Each site measured continuous ozone (O_3) concentrations and meteorological conditions and measured weekly average particulate sulfate (SO_4^{2-}), particulate nitrate (NO_3^-), particulate ammonium (NH_4^+), SO_2, and nitric acid (HNO_3) concentrations. Selected sites collected precipitation samples that were analyzed for acidity and related species. In addition, a 10-station visibility monitoring network was established in 1994 as part of CASTNet. A three-station Mountain Acid Deposition Program (MADPro) was also instituted in 1994.

Currently, CASTNet operates 45 eastern and 3 western dry deposition sites and 21 sites that measure precipitation chemistry. The MADPro and visibility networks are operational. Other measurement programs have also been instituted as part of the overall CASTNet.

This report summarizes the analysis and interpretation of NDDN and CASTNet measurements taken from 1987 through 1995. The extensive database of concentrations and calculated dry, wet and total depositions has been analyzed. Distributions and trends of depositions of sulfur and nitrogen species are presented for the eastern United States. Ozone concentrations and related exposure statistics are presented and analyzed in terms of existing and proposed national air quality standards. Data and initial results from the visibility monitoring and Mountain Acid Deposition Program (MADPro) are reviewed.

At the beginning of NDDN and continuing with CASTNet, EPA established rigorous objectives for the accuracy and precision of the field and laboratory data. The network responded by instituting a strong quality assurance/ quality control (QA/QC) program, which has resulted in the CASTNet data largely meeting the stated precision and accuracy goals. In short, the CASTNet data constitute an exceptional database for the purpose of discerning status and trends in air quality and of supporting other scientific activities. Furthermore, the results from the QA/QC program demonstrate conclusively that the observed changes in concentrations and depositions are real and not the result of network modifications or of data imprecision or inaccuracy.

CASTNet measurements collected from 1989 through 1995 are able to detect trends in concentrations of acid gases and aerosols. Preliminary trends analysis using simple statistical procedures and not accounting for variations in meteorology show statistically significant reductions in annual SO_2, SO_4^{2-}, and HNO_3 concentrations. A direct comparison of 1989 and 1995 annual concentrations averaged over all eastern sites (not accounting for the year-to-year variations in annual concentrations between 1989 and 1995) show a 23-percent reduction in SO_4^{2-} and a 43-percent reduction in SO_2. Extending the trend analysis by including measurements from the Sulfate Regional Experiment (SURE) reinforces the demonstration of a significant downward trend in SO_4^{2-}. The eastern data indicate about 70 percent of ambient sulfur is in the form of SO_2. In contrast, the SURE data indicate that more than 90 percent of ambient sulfur was SO_2.

Concentration data show a slight decline (6 percent) in HNO_3 levels. No trends are observed in annual concentrations of NO_3^-. HNO_3 contributes about 65 percent of ambient nitrogen throughout CASTNet. Data collected in the western network exhibit no trends.

A micrometeorological model called the multilayer model (MLM) was used to simulate deposition velocities for the measured ambient species. Dry depositions were then calculated as the product of concentrations and deposition velocities. An analysis of the uncertainties in simulated deposition velocities suggest that the MLM underestimates observed deposition velocities and, consequently, dry depositions by an unquantified amount. The calculated dry deposition values discussed in this report do not account for quantified uncertainties and represent lower bound estimates only.

Calculated annual dry depositions show downward trends for the sulfur species although the trend lines are not considered statistically significant. The eastern data show a 29-percent reduction of SO_2 (as sulfur) and only a 6-percent reduction in deposition of SO_4^{2-}. The eastern data indicate about 85 percent of sulfur deposition is in the form of SO_2. No trends are apparent for the eastern-average nitrogen dry depositions or in the depositions calculated for the western sites. These trends results do not account for year-to-year variations in meteorology.

CASTNet precipitation chemistry data were supplemented by National Atmospheric Deposition Program (NADP) data collected at sites approximately collocated with CASTNet sites without precipitation sampling. Annual concentrations in precipitation of SO_4^{2-} show an overall decline throughout the eastern network, although the results are not considered statistically significant. Similarly, NO_3 data show downward trends, but the results are not significant.

Sulfate wet depositions averaged over all eastern sites show a 35-percent reduction over the period 1989 to 1995. The results are considered statistically significant. Nitrate wet depositions show about a 20-percent reduction over the 7-year period, although the results are not considered statistically significant.

The CASTNet database presents the opportunity for the first time to investigate trends in total (wet plus dry) deposition of sulfur and nitrogen species and contrast the results with trends in emissions. Total deposition of atmospheric sulfur (Figure ES-1) averaged over all CASTNet eastern sites has decreased by 32 percent from 1989 through 1995. Nationwide SO_2 emissions have declined according to EPA (1996) by 22 percent from 1985 through 1995. Electric utility SO_2 emissions have dropped by 24 percent over that same period. A dramatic drop in SO_2 emissions has been reported (EPA, 1996) from 1994 to 1995. Nationwide SO_2 emissions have dropped 13 percent and utility emissions 17 percent in 1 year. NO_x emissions have been relatively flat since 1970. However, a 8-percent reduction in overall NO_x emissions and a 21-percent reduction in electric utility NO_x emissions was reported between 1994 and 1995. Despite these reported recent emission reductions, the CASTNet data show no change in total deposition of nitrogen from 1989 through 1995. Once again, these results do not account for year-to-year variations in meteorology or for quantified model uncertainties.

The CASTNet O_3 data provide estimates of exposure statistics and allow gauging compliance with the National Ambient Air Quality Standards (NAAQS) for O_3. After 1988, violations of the 1-hour standard were limited to suburban sites in the Washington-New York corridor. Concentrations above the new 8-hour standard of 85 parts per billion (ppb) were measured throughout the midwest and northeast and at a few south-central sites. The measure SUM06 had been suggested as a secondary standard for O_3. During 1989 through 1995, many CASTNet sites show SUM06 values above 25 parts per million hours (ppm-hr), the proposed numerical limit.

EPA has proposed creating a new NAAQS for fine particles smaller than 2.5 microns in diameter. The final EPA proposal would limit 24-hour values to 65 micrograms per cubic meter ($\mu g/m^3$) and annual values to 15 $\mu g/m^3$. The CASTNet visibility network was created to measure the character and composition of fine particles and other parameters related to visual air quality. Measurements taken in 1994 show a strong relationship between fine particle mass and fine SO_4^{2-} concentrations. Fine SO_4^{2-} is a major contributor to fine particles in the eastern United States. SO_4^{2-} particles are the major contributor to fine particle mass in the summer months. Fine nitrate and carbon particles play a more significant role in the winter. Fine SO_4^{2-} contributes more than 85 percent of the mass of total particulate SO_4^{2-}, which has been shown to be declining in the eastern United States. The rural CASTNet measurements show compliance with the proposed 24-hour and annual fine particle mass standards.

MADPro is a component of CASTNet designed to study over several years the deposition of air pollutants to high elevation forests. MADPro objectives are to measure cloud chemistry, determine total deposition, and define source regions that impact high elevation ecosystems in the eastern United States. The results to date show that cloudwater can be the primary pathway for deposition of air pollutants.

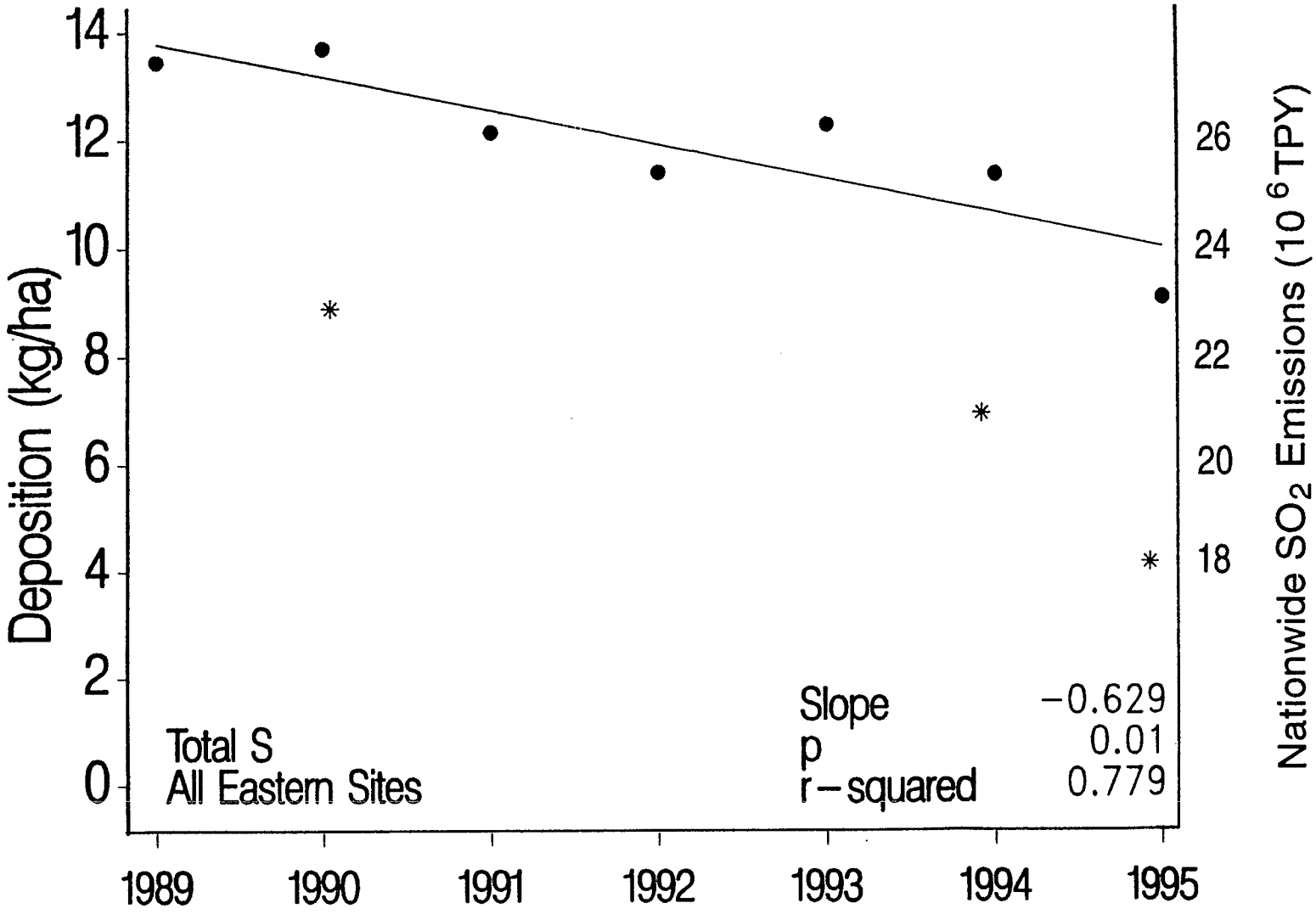


Figure ES-1. Linear regressions of total sulfur depositions versus year for all eastern sites combined

Note: Emissions are indicated by a *.

Chapter 1
Introduction

Atmospheric deposition takes place via two pathways: wet deposition and dry deposition. Wet deposition is the result of precipitation events (rain, snow, etc.) which remove particles and gases from the atmosphere. Dry deposition is the transfer of particles and gases to the landscape through a number of atmospheric processes in the absence of precipitation. Wet deposition rates of acidic species across the United States have been well documented over the last 10 to 15 years; however, comparable information is unavailable for dry deposition rates. This lack of information on dry deposition increases the uncertainty in estimates of interregional, national, and international transport and confounds efforts to determine the overall impact of atmospheric deposition.

The direct measurement of dry deposition is not straightforward, but a number of investigations have shown that it can be reasonably inferred by coupling air concentration data with routine meteorological measurements (Shieh *et al.*, 1979; Hicks *et al.*, 1985; Meyers and Yuen, 1987; Wesely and Lesht, 1988). Shieh *et al.* (1979) have shown that submicron particle and sulfur dioxide (SO_2) deposition rates for the eastern United States were strongly dependent on windspeed, solar radiation, and the condition and type of ground cover. For example, rapidly growing vegetation and forests were found to generally experience higher deposition rates than senescent vegetation, short grass, or snow. This approach has been expanded (Wesely, 1988) to calculate deposition rates for various additional atmospheric species using site-specific meteorological data.

In 1986, the U.S. Environmental Protection Agency (EPA) contracted with Environmental Science & Engineering, Inc. (ESE) [currently known as QST Environmental Inc. (QST)] to establish and operate the National Dry Deposition Network (NDDN). The objective of the NDDN was to obtain field data at approximately 50 sites throughout the United States to establish patterns and trends of dry deposition. The approach adopted by the NDDN was to estimate dry deposition using measured air pollutant concentrations and modeled deposition velocities (V_ds) estimated from meteorological, land use, and site characteristic data. The model currently used for dry deposition calculations is a multi-layer version of the Big Leaf Model developed by Meyers *et al.* (1991).

Passage of the Clean Air Act Amendments (CAAA) in 1990 required implementation of a national network to monitor the status and trends of 1) air emissions, pollutant deposition, and air quality; 2) determine the effects of emissions on water quality, forests, and other sensitive ecosystems; and 3) assess the effectiveness of emission reduction requirements through operation of a long-term monitoring program. In response to these requirements of the CAAA, the EPA, in coordination with the National Oceanic and Atmospheric Administration (NOAA), created the Clean Air Status and Trends Network (CASTNet). CASTNet became operational in mid-1991, and the NDDN program was incorporated into CASTNet at that time. To increase spatial representation of CASTNet for the western United States, EPA and the NPS agreed to share responsibilities in the operation of 19 NPS monitoring sites for the measurement of dry deposition.

This report summarizes results of NDDN and CASTNet monitoring activities from 1987 through 1995. Concentration and deposition data for atmospheric sulfur and nitrogen species are presented and discussed as grand averages for the entire time period as well as annual averages for 1989, 1992, and 1994. Annual and seasonal averages for each year are discussed regionally. Relative contribution of gases versus aerosols are evaluated. Wet deposition data for 21 CASTNet and 38 National Atmospheric Deposition Program (NADP) sites are presented and then used, along with dry deposition calculations, to estimate total depositions of sulfur and nitrogen. The relative magnitude of wet and dry deposition are discussed. Ozone (O_3) concentrations and exposure statistics are illustrated for 1989, 1992, and 1994 and analyzed for the entire monitoring record.

Data and results from the visibility and mountain acid deposition programs are briefly discussed. The mobile system for the direct measurement of dry deposition is described along with field studies in which the system was successfully utilized. Initial results of the comparison between filter packs and annular denuders is also given.

Chapter 2

Network Description and Methods

2.1 Network Description

Figure 2-1 shows the locations of current and historical CASTNet Deposition Network (CDN) sites. Forty-five primarily rural eastern sites and three western sites are currently operational (sites with 100 series designations). Two of the eastern sites are collocated for assessment of network precision. Eighty-one percent of the network was installed and collecting data as of July 1989. The remaining nine sites came online between July 1990 and July 1995. Eleven sites were discontinued from October 1988 through December 1993, mostly due to less than ideal siting conditions. Table 2-1 lists all of the CASTNet sites, their locations, and dates of operation. In December 1995, the number of CDN sites was reduced to 15 due to funding limitations, with 13 sites in the eastern United States and 2 sites in the western United States. In June 1996, funding was restored, and most of the original sites were reactivated, returning the network to its original configuration. The number of sites in the network is summarized by year in Table 2-2.

In 1994, the EPA and National Park Service (NPS) began a collaborative effort to expand dry deposition measurements in the western United States [primarily at National Parks (NP) and Monuments]. EPA agreed to provide operating protocols, assistance with equipment installation, data management, and reporting, while NPS agreed to support field operations, laboratory analysis, and quality assurance (QA). As of May 1997, 19 NPS sites were installed and operational (sites with 400 series designations). During this period, one eastern and three western CASTNet sites were operationally turned over to the NPS.

As part of routine network operations, data are collected at a site in Egbert, Ontario, Canada to determine if measurement biases exist between the United States and Canadian dry deposition systems. This site is currently occupied by two Canadian trends monitoring networks [Canadian Acid Deposition Monitoring Network (CAPMoN) and Acid Precipitation in Ontario Study (APIOS)].

Wet deposition samples are collected at 18 eastern and 3 western CDN sites and 1 network intercomparison site [NADP/National Trends Network (NTN), CAPMoN, CASTNet] at Scotia Range, PA.

2.1.1 Site Selection

The current network is designed to support investigation of relationships between emissions and atmospheric concentrations/depositions. Assessments of sensitivity to O_3 and acid deposition have shown that large areas of potentially sensitive terrestrial and aquatic ecosystems exist in the eastern United States and that limited areas of sensitive ecosystems exist in the western United States. These findings, coupled with the expected changes in emissions of sulfur oxides (SO_x) and nitrogen oxides (NO_x), underlie the distribution of sites in the network. Each of the eastern United States monitoring sites was selected by considering:

1. Regional representativeness,
2. Long-term availability, and
3. Accessibility.

For the western United States, the limited number of sites and higher diversity of the region precluded determination of spatial patterns. Therefore, site selection focused primarily on locations where specific research issues could be addressed and where natural resources were at risk (e.g., national parks). These locations included calibrated watersheds, in which dry deposition information was needed to close geochemical cycles for sulfur, nitrogen, and alkalinity.

Regional representativeness refers to the overall similarity of the site to a characteristic area [typically 80 by 80 kilometers (km)] surrounding the site. This implies that concentrations must also be representative. Thus, major sources of SO_x and/or NO_x were avoided to reduce the likelihood of locally perturbed concentration fields. In addition, land use near the site matches, as much as possible, the dominant regional land use to make appropriate use of meteorological data in V_d calculations. Finally, monitoring sites needed to be available for extended periods (10 to 15 years) in order to assess dry deposition trends.

Site-specific criteria relate to conditions in the immediate vicinity of a prospective monitoring site. Specifically, they concern local features that may perturb air quality and meteorological

observations. Local sources of air contaminants and local features that may influence windspeed, wind direction, etc. are the focus of these criteria. A list of site-specific criteria that are used during the site-selection process is shown in Table 2-3.

An iterative procedure for selecting dry deposition monitoring sites was followed. The major steps include:

1. Identification of general areas for inclusion in the network;
2. Review of emission inventory, population, and land-use data to identify areas that are regionally representative;
3. Visits to the areas identified in Step 2 to identify and document candidate sites; and
4. Selection of measurement sites by the EPA Project Officer.

By design, the network attempts to capture anticipated gradients in atmospheric pollutants (especially SO_2). Thus, the northeastern sites are closely spaced around emission sources in the Ohio River valley and more distantly spaced throughout New England and the Atlantic coast states. Network spacing is still greater in the southeast and west, where emission densities (and expected gradients) are considerably lower than in the northeast.

2.1.2 Subregions

For presentation purposes, sites in the eastern United States have been grouped into six subregions (see Figure 2-2). Subregional designations, with numbers of sites in parentheses, are as follows: northeast (11), upper northeast (3), midwest (9), upper midwest (3), south central (11), and southern periphery (3). Besides geographic location, site groupings were based on terrain and general spatial patterns of atmospheric concentration data. The categorization of sites also divides the Appalachian Mountains into three convenient geographic ranges. The northern Appalachians, including the Adirondack Mountains of New York, the Green Mountains of Vermont, and the White Mountains of New Hampshire fall within the upper northeast subregion. The central Appalachians, including the Catskill Mountains of New York, and the Allegheny Mountains of West Virginia, fall within the northeast subregion. Finally, the southern Appalachians, including the Great Smoky Mountains of North Carolina and Tennessee and the Blue Ridge Mountains of Virginia, fall within the south central subregion. Each of these subregions thus includes sites in mountainous areas, both for the

purpose of monitoring deposition in sensitive areas and to elucidate variability of deposition in complex terrain.

Sites in the upper northeast subregion are exclusively rural-forested, while those in the northeast subregion exhibit a range of characteristics. Six northeastern sites are rural-forested, two are rural-agricultural (106 and 128), and three are near or within the Washington-Baltimore-Philadelphia-New York City conurbation (104, 116, and 144). The upper midwest sites are rural-agricultural or rural-forested (149). The midwest sites are rural-agricultural, except for Site 146 (suburban Chicago), which is urban-agricultural. Although rural in character, three sites (122, 140, and 157) are influenced, to a greater or lesser extent, by SO_2 emissions from nearby point sources with annual emissions in excess of 1,000 tons per year (tpy).

The south-central sites are either rural-forested or rural-agricultural but exhibit a wide range of terrain characteristics. Three sites are located above 1,000 m and form a line extending from northern Virginia to southwestern North Carolina. Site 118 (currently NPS Site 418) is situated on a ridge of the eastern Blue Ridge Mountains, and Sites 120 and 126 occupy the spine of the Appalachian Mountains. Due to the unique exposure of these sites, they have been placed in a separate terrain category (i.e., mountaintop). Two sites (121 and 137) are located in hollows or valleys, and the other six sites in the subregion are in rolling terrain. The distribution of sites in this subregion provides an opportunity to investigate relationships among terrain characteristics, atmospheric concentrations, and dry deposition (see Section 3.0). Finally, all three of the southern periphery sites are rural-forested in flat or rolling terrain.

Despite apparent similarities in land use and terrain, the western sites are not homogeneous in character. For this reason, no attempt was made to group western sites. Site 161 (Gothic, CO) occupies a mountain valley within the central Rocky Mountains. Site 162 is located on the foothills of the High Uintas, the most prominent east-west mountain range in North America. Sites 163 and 164 are located in semi-arid rangeland near the northern extreme of the Great Basin. Sites 165 and 169 represent the transition from the western Great Plains to the Rocky Mountains. Sites 167 and 174 are located in the arid southwest; Site 167 is in the Sonoran Desert, while Site 174 is on the extensive and forested Kaibab Plateau. Site 168 (near the Canadian border) alone represents the western boreal forest. Thus, although these sites are

collectively termed the western part of the network, they represent a wide range of environments.

Site locations and descriptive information are provided in Table 2-4. Terrain and land-use information refers to a 10-km radius around the site and is presented to convey a sense of the setting within which each site operates. Site numbers are used for identification purposes only and do not correlate with order of installation or operation.

2.2 Methods

This section provides a brief overview of the CDN methods. Step-by-step protocols and additional details on these activities can be found in the CDN Field Operations Manual, Laboratory Operations Manual, and Data Management Manual (ESE, 1990a, 1990b, 1991a).

2.2.1 Field Operations

Ambient measurements for O_3, SO_2, particulate sulfate (SO_4^{2-}), particulate nitrate (NO_3^-), nitric acid (HNO_3), particulate ammonium (NH_4^+), and meteorological variables required for dry deposition calculations are performed at each CDN site. Meteorological variables and O_3 concentrations are recorded continuously and reported as hourly averages consisting of a minimum of nine valid 5-minute averages. Atmospheric sampling for sulfur and nitrogen species is integrated over weekly collection periods using a 3-stage filter pack (Figure 2-3). In this approach, particles and selected gases are collected by passing air at a controlled flow rate through a sequence of Teflon®, nylon, and Whatman filters. The Teflon® filter removes particulate SO_4^{2-}, NO_3^-, and NH_4^+, and the nylon filter is used to remove HNO_3. The Whatman filter is a cellulose filter base that is impregnated by potassium carbonate (K_2CO_3) and is used for removal of SO_2. In practice, a fraction (usually <20 percent) of ambient SO_2 is captured on the nylon filter. The nylon filter SO_2 and Whatman filter SO_2 are therefore summed to provide weekly average concentrations. The nylon filter HNO_3 is converted to NO_3^- and added to the Teflon® filter NO_3^- to provide weekly total NO_3^- concentrations.

Filter packs are prepared and shipped to the field weekly and exchanged at each site every Tuesday. Blank filter packs are collected monthly to evaluate passive collection of particles and gases as well as contamination during shipment and handling. At 21 sites located more than

50 km from NADP/NTN sites (Figure 2-4), wet deposition samples are collected weekly (according to NADP/NTN protocols) and shipped to QST for chemical analysis.

Filter pack sampling and O_3 measurements are performed at 10 m using a tilt-down aluminum tower (Aluma, Inc.). Filter pack flow is maintained at 1.50 liters per minute (Lpm) at eastern sites and 3.00 Lpm at western sites, for standard conditions of 25 degrees Celsius (°C) and 760 millimeters of mercury (mmHg) with a mass flow controller (MFC). Wet deposition samples are collected in precleaned polyethylene buckets using an Andersen Model APS precipitation sampler. Buckets are placed on the sampler on Tuesday and removed, whether or not rainfall has occurred, the following Tuesday. Buckets are weighed in the field, decanted to a 1-liter (L) polyethylene bottle, sealed, and shipped to QST for chemical analysis. Precipitation amount (depth) is also monitored at wet deposition sites. Figure 2-5 depicts a typical CDN site configuration.

O_3 is measured via ultraviolet (UV) absorbance with a Thermo-Environmental Model 49-103 analyzer operating on the 0- to 500-part per billion (ppb) range. Ambient air is drawn from the 10-m air quality tower through a 3/8-inch TFE Teflon® sampling line. Teflon® filters housed at the tower inlet and the analyzer inlet prevents particle deposition within the system. Periodic checks indicate that online losses through the inlet system are consistently less than 3 percent. Zero, precision (60 ppb), and span (400 ppb) checks of the O_3 analyzer are performed every third day using an internal O_3 generator.

In addition, various observations are periodically made at the CDN sites to support model calculations of dry deposition. Site operators record surface conditions (e.g., dew, frost, snow) and vegetation status weekly. Vegetation status and land-use information are used to define the distribution and condition of plant species around each site that could influence deposition rates for gases (especially SO_2) and particles. Vegetation data are obtained to track evolution of the dominant plant canopy, from leaf emergence (or germination) to senescence (or harvesting). Once a year, site operators also provide information on major plant species and land-use classifications within 1.0 km of the site. Additional land-use data was obtained by digitization and analysis of aerial photographs obtained from the U.S. Geological Survey (USGS) National Cartographic Information Center in Reston, VA. Photographs were interpreted according to procedures described by Anderson *et al.* (1978).

Leaf area index (LAI) measurements were taken at all CDN sites during the summers of 1991 and 1992. LAI is the one-sided leaf area of the plant canopy per unit area of ground at full leaf emergence and has been shown to play an important role in atmosphere-canopy exchange processes (McMillen, 1990). LAI is measured using an LAI-2000 Plant Canopy Analyzer manufactured by Li-Cor (Lincoln, NE). The LAI-2000 makes indirect (i.e., nondestructive) estimates of LAI from simultaneous measurements of light interception by the plant canopy at five angles of inclination (Li-Cor, 1989). Initial development and testing of the LAI-2000 by the manufacturer focused on a variety of agricultural crops, such as soybeans and wheat, and similar approaches have been used to measure LAI of forest canopies (Pierce and Running, 1988; Chason *et al.*, 1990).

All field equipment is subjected to quarterly inspections and multipoint calibrations, using standards traceable to the National Institute of Standards and Technology (NIST). In addition, independent equipment audits were performed annually by Ogden Environmental and Energy Services, Inc. (Ogden), and randomly by EPA or its designee. Results of field calibrations are used to assess sensor accuracy and flag, adjust, or invalidate field data. Precision and accuracy criteria for CDN field measurements are shown in Table 2-5.

2.2.2 Laboratory Operations

Filter pack samples are loaded, shipped, received, extracted, and analyzed by QST personnel at the Gainesville, FL laboratory. Filter packs contain three types of filters in sequence: a Teflon® filter for collection of aerosols, a nylon filter for collection of HNO_3, and dual K_2CO_3-impregnated cellulose filters for collection of SO_2.

Following receipt from the field, exposed filters and blanks are extracted and then analyzed for SO_4^{2-} and NO_3^- by micromembrane-suppressed ion chromatography (IC). Teflon® filter extracts are also analyzed for NH_4^+ by the automated indophenol method using a Technicon II or TRAACS-800 Autoanalyzer system. All analyses are completed within 72 hours of filter extraction. Figure 2-6 depicts the sequence of laboratory operations for filter pack sample analyses.

Wet deposition samples are filtered and then analyzed for pH, conductivity, acidity, sodium (Na^+), potassium (K^+), NH_4^+, calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), nitrite (NO_2^-),

NO_3^-, and SO_4^{2-}. Analysis of NH_4^+ and anions is as described previously for filter pack samples. Analysis of Na^+, Mg^{2+}, and Ca^{2+} is performed with a Perkin-Elmer P-2 inductively coupled argon plasma (ICAP) emission spectrometer. Acidity is determined via titration to approximately pH 8.3, and K^+ was analyzed via atomic emission through first quarter 1995 and subsequently via ICAP. Table 2-6 lists the analytes per sample plus the QC solutions for periods of record. Figure 2-7 depicts the sequence of laboratory operations for wet deposition sample analyses.

Results of all valid analyses are stored in the laboratory data management system [Chemistry Laboratory Analysis and Scheduling System (CLASS™)]. Atmospheric concentrations are calculated (based on volume of air sampled) following validation of hourly flow data. Atmospheric concentrations of particulate SO_4^{2-}, NO_3^-, and NH_4^+ are calculated based on the analysis of Teflon® filter extracts; HNO_3 is calculated based on the NO_3^- found in nylon filter extracts; and SO_2 is calculated based on the sum of SO_4^{2-} found in nylon and cellulose filter extracts.

2.2.3 Data Management

The Data Management Center (DMC) activities consists of four major operations: data acquisition, data validation, model operation, and transmittal to EPA. These activities are described briefly in this section. Details on data management and operation of the Multi-Layer Dry Deposition model are provided in the CASTNet Data Management Manual, the paper by Clarke and Edgerton (1993), and in Section 3.1.2.

The data acquisition process stresses multiple levels of redundancy to minimize data loss. The primary mode of data acquisition from the field is via telephone modem. Each site is automatically polled by the DMC between 2:00 and 5:00 a.m. every day using an IBM-compatible PC and software developed by Odessa Engineering, Inc. The polling software permits recovery of hourly data and status files, power failure logs, and automated calibration results from the previous 7 days. The program also maintains synchronization of the network by checking the clock within each data acquisition system (DAS) and correcting the time if it deviates from expectation by more than 5 minutes. If daily polling results in incomplete data capture from any site, then diskettes of data from the primary and backup DAS are read into the database management system. If the database is still incomplete, missing data are entered

manually either from site printouts or recovered from data cartridges. Each datum is automatically given a source flag that is used to trace its mode of entry into the system (i.e., modem, cartridge, or manual entry).

At each site, an Odessa DSM-3260 interfaced with a Turbo XT PC (compatible with an IBM XT) comprises the primary DAS. The DAS collects and processes data from the station sensors and instruments; averages, flags, and stores the data; transmits data upon command; and generates standard reports. Activation of the zero/span/precision sequence of the O_3 analyzer is also controlled by the DAS. The DAS records hourly averages in a 16K internal random-access memory (RAM) and on a 128K external data cartridge. The 16K internal RAM and the 128K cartridge hold approximately 7 and 90 days of hourly data, respectively. Sixteen channels of data can be input into the DSM-3260. Currently, 12 input channels are assigned for precipitation, vector-averaged wind direction and windspeed, temperature, delta temperature (lapse rate), relative humidity, O_3 (two channels), solar radiation, filter pack flow rate, scalar-averaged windspeed, and wetness. For the Mountain Acid Deposition Program (MADPro), one channel is used to collect cloud presence data. Cloud presence is defined as a 5-minute period with an average liquid water content of at least 0.05 gram per cubic meter (g/m^3). Standard deviation of wind direction (sigma theta) is calculated as 15-minute averages of 1-second readings. Four consecutive 15-minute averages are then averaged to produce hourly values.

The onsite PC serves as a terminal for communicating with the DAS and allows the site operator to:

1. Review hourly averages and instantaneous values,
2. Review the status of initialization functions and control outputs, and
3. Download data for transmittal to QST.

Data are downloaded from the data cartridge to a floppy disk that is mailed to QST. A backup copy of the data is retained onsite. In addition, a dot-matrix printer provides a hard copy of hourly data and site operator interactions with the DAS. Printouts are sent to QST the first Tuesday of every month.

An Odessa DSM-3260L is used as the backup DAS. The 3260L is equipped with a 128K RAM cartridge, which can store approximately 3 months of hourly averages from eight input

channels. The channels recorded on the backup DAS are windspeed, wind direction, relative humidity, solar radiation, O_3, temperature, delta temperature, filter pack flow, and sigma theta.

In summary, the continuous data are transmitted from CDN sites to the DMC via:

1. Daily dial-up of each site by modem,
2. A disk with hourly averages from the DSM-3260,
3. Hard-copy printouts from the PC XT, and
4. A backup disk with hourly averages from the DSM-3260L.

The CDN database management system (DBMS) consists of a custom version of Odessa Engineering's Environmental Aide software. The Environmental Aide system consists of two programs, ENVICOM and ENVAID, which reside on a Local Area Network (LAN) in the DMC.

ENVICOM is a communications and data transmittal package that contains configuration parameters for up to 100 remote stations. The primary function of ENVICOM is to poll each site daily and incorporate the previous day's hourly averages into the raw database. When ENVICOM calls a DAS, it instructs the unit to transmit the data 1 hour at a time for all parameters. Check sums are embedded in each string to verify error-free transfer. If errors are detected, data will be replaced with a missing code. At each poll, ENVICOM attempts to replace missing values for the past week with valid information.

Data retrieved through ENVICOM are entered directly into the raw database and stored in binary data and status files. ENVICOM is also used to ingest cartridge data that have been transferred to disk. Information that has been recorded on the disk, but is missing in the ENVICOM database, will automatically be inserted, replacing only missing periods.

ENVAID consists of data management software that provides capabilities to edit the data and status files, run simple statistical analyses, and manually enter missing data. When the data have been reviewed and validated, a third program, REPORTS, is used to present the data in readable summaries. REPORTS is also used to convert the edited binary database into ASCII format, which is copied to a high-density disk for database transmittal.

The process of data validation begins within hours after the stations are polled. Daily summaries are generated as data are collected from the sites. Field operations personnel then review these reports daily and detect potential problems with minimal delay. Site Status Report Forms (SSRFs) and operator logsheets are reviewed weekly to verify the validity of the data received. When data for 1 month have been collected from all means available, those data are considered to be validated at Level I.

Level II validation involves a more detailed screening of the data. SSRFs, operator logsheets, calibration data, and audit results are all reviewed for each site. This is the most labor-intensive step since defensible decisions need to be made. In addition, data are screened using the automated program VCHECK, which identifies potential problems such as values greater than the expected range and invalid combinations of status flags, values, and spikes. All review and editing activities which take place in the DMC are documented. When a monthly data set for a site is reviewed, the data analyst records recommended changes along with reasons on a Change Documentation Review Form (CDRF). The data management supervisor reviews these changes, consulting the QST Work Assignment Manager as necessary, and passes approved changes along to the data management personnel. The times and dates of all changes are recorded on the CDRF entry form by the person who makes the changes.

When all documentation has been reviewed and the database has been edited to the satisfaction of the data management supervisor, the project QA supervisor reviews approximately 10 percent of the database for traceability. Upon completion of the QA review, the data management supervisor, project QA supervisor, and work assignment manager deem the database as validated at Level II.

Data generated from filter pack samplers, precipitation samplers, and cloudwater samplers is managed by CLASS™. Figure 2-8 depicts the flow of data management activities that are handled by CLASS™.

Attainment of Level I validation for discrete data consists of meeting the following criteria:

1. Data are determined to be reasonable based on the analyst's evaluation of the data batch QC sample results.

2. Data transfer by electronic or manual entry into CLASS™ is completed properly as evaluated by the Laboratory Operations Manager.
3. The appropriate analytical batches are processed through an automated QC checking routine performed by CLASS™ and determined to be acceptable. For each analytical batch, an alarm flag will be generated if any of the following occurs.
    a. Insufficient QC data are run for the batch.
    b. Correlation coefficient of standard curve is less than 0.995.
    c. The 95-percent confidence limit of the Y-intercept exceeds the limit of quantitation.
    d. Sample response exceeds the maximum standard response in the standard curve (i.e., the sample must be diluted to bring the response within the range of the curve).
    e. Continuing verification samples (CVSs) exceed the recovery limits.
    f. Reference samples exceed accuracy acceptance limit.

A batch with one (or more) flags can be accepted only if written justification is provided by the Laboratory Operations Manager.

To calculate atmospheric concentrations from filter pack samples, filter pack flow data are merged with laboratory data. Atmospheric concentrations are calculated only if valid hourly averages for filter pack flow represent at least 75 percent of the sampling period and analytical data meet all QC criteria. Filter pack samples with greater than 75 percent but less than 90 percent valid flow data will be flagged to indicate uncertainty in concentration calculations.

For wet deposition samples, a second laboratory data validation check involves three interparameter consistency checks:

1. Percent difference of cations versus anions,
2. Percent difference of predicted-versus-measured conductivity, and
3. pH-versus-conductivity relationship of the sample compared to the expected relationship when rainfall is assumed to be controlled by sulfuric acid.

The evaluation of these interparameter consistency checks provides a method for determining whether the analysis should be repeated or verified.

CLASS™ has been programmed to calculate cations, anions, and predicted conductivity. Percent ionic and conductivity difference values are calculated by the following equation:

$$Percent\ difference = 200 \times \frac{(V_1 - V_2)}{(V_1 + V_2)} \quad (2\text{-}1)$$

The criterion for re-analysis is:

a. Percent ionic difference of cations (Value 1) versus anions (Value 2):

   If pH <4.8, then criterion = ± 15 percent

   If pH >4.8, then criterion = ± 30 percent

b. Percent conductivity difference for predicted (Value 1) versus measured (Value 2) conductivity:

   If conductance <10, then criterion = ± 30 percent

   If conductance >10, then criterion = ± 10 percent

Figure 2-9 shows the flow of data through the entire data management system.

Attainment of Level II validation requires that:

1. All Level I data meeting QC criteria are reviewed and evaluated as acceptable by the Laboratory Operations Manager.
2. A review and evaluation of any alarm flags is completed by the Laboratory Operations Manager.
3. Written justification for acceptance of data that did not meet QC criteria is approved by the QA Supervisor.
4. SSRFs and Precipitation Sample Report Forms (PSRFs) are reviewed.
5. As received from the DMC, valid flow data are processed and checked before calculation of atmospheric concentrations.
6. Atmospheric concentrations are calculated as follows:

$$Volume\ in\ m^3 = \frac{total\ sample\ time\ (hr) \times average\ flow \times 60}{1{,}000} \quad (2\text{-}2)$$

$$Atmospheric\ Concentration\ in\ \mu g/m^3 = \frac{\mu g\ of\ analyte/filter \times analyte\ dependent\ constant\ (if\ necessary)}{volume} \quad (2\text{-}3)$$

$$Constant = \frac{molecular\ weight\ of\ analyte\ in\ air}{molecular\ weight\ of\ corresponding\ element\ (e.g.,\ S\ or\ N)\ in\ solution} \quad (2\text{-}4)$$

Note: m^3 = cubic meter.
μg = microgram.

7. The CDN transfer file and flag counts are submitted to and confirmed by the data management staff.

Within 120 days after the end of a quarter, the Level II database is submitted in ASCII format on a high-density 3½-inch diskette along with hardcopy printouts and a quarterly data report. Every file submitted to EPA is accompanied by a QC report, which lists parameter averages by site and aggregated counts of status flags. The quarterly data report summarizes network activities in the period and presents results of all field and laboratory QC checks. Results of traceability audits by the project QA supervisor are also presented.

2.2.4 Quality Assurance

The CDN QA program is a comprehensive program that addresses all major aspects of project operations. Tables 2-7 and 2-8 list the routine QA audits performed at CDN sites and the QST laboratory, respectively.

2.2.4.1 Field Data Audits

Level II Database Audit

Since transmission errors have been shown to be extremely rare, this audit focuses on documentation, validation, and manual entry operations.

Field data are validated in monthly batches, and approximately 5 percent of these monthly validation batches is selected at random for audit purposes. Another 5 percent is selected that involve a high degree of data entry and manipulation. Since there are typically 165 batches (three monthly batches for 55 sites), 17 batches are selected. Each monthly data batch is accompanied by a CDRF, which documents all changes made to the database during the validation process. Each transaction documented on the CDRF of the selected batch is verified

by review of the corresponding Level II database as well as review of all calibration information.

Corresponding portions of the database are also reviewed to detect undocumented or inadvertent changes that would not appear on the CDRF. This is accomplished by ensuring that all data source flags are correlated with CDRF entries. Data source flags indicate the mode of entry of each datum into the database. Any numeric value or status flag manually entered or modified is prefixed with an "m" source flag. All errors and cases of confusing documentation are discussed with the DMC manager and staff. A review of completeness, discrepancies found, and resulting corrective actions are reported.

QC Failure Audit

This audit includes a review of all reported problems with sensors and equipment at the sites and the actions taken to solve such problems. Calibration result summaries, external audit spot reports, and mail-out audit results are reviewed as well. Calibration results and problem reports for the site-months audited during the Level II database audit are cross-referenced with the CDRFs and the database to ensure that the validation process includes required updates.

Field Calibrator Audit

The QA supervisor observes field calibration and conducts a systems audit of the monitoring site.

Field Calibration Data Audit

Calibration files of the Level II audit sites are reviewed for completeness of the calibration information, manual entry, transcription errors, and standard operating procedures (SOPs). Certification results are also reviewed, and transfer sensor serial numbers are cross-referenced with the transfer sensor serial numbers on the calibration forms.

2.2.4.2 Laboratory Data and Operations Audits

The laboratory component of the QA audit addresses data obtained from filter packs collected at all CDN sites and wet deposition samples collected at selected sites. Six types of QA checks are performed to evaluate the following:

1. Traceability of data from analytical instruments to CLASS™,

2. Validity of filter pack flow calculations used to determine atmospheric concentrations,
3. Status of filter media acceptance tests and chain-of-custody audits,
4. Accuracy of precipitation field data including review of rain gauge charts,
5. Compliance with overall data requirements for the project, and
6. Life history audits.

The procedure for each of these checks is outlined as follows:

1. Laboratory Recalculation Audit:
   a. The audit for filter pack analytes is conducted by randomly selecting 20 percent of all data batches analyzed for the quarter. Calibration curves for selected batches are regenerated from raw analytical data (MAXIMA) and compared with CLASS™ printouts.
   b. Concentrations of filter pack analytes determined by IC are recalculated using the raw data from MAXIMA for analyte response and calibration curves (generated in Step a), then compared with CLASS™ concentrations.
   c. The concentration of NH_4^+ in wet deposition samples and Teflon® filter extracts, analyzed by TRAACS, is audited by recalculating the coefficients of the quadratic regression equation, followed by recalculation of every tenth sample in the batch.
   d. The audit for wet deposition analytes is conducted by selecting between 20 and 40 percent of batches analyzed for the quarter. The percent selected depended on the number of batches run per analyte grouping, but in all cases at least one batch is selected.
   e. Concentrations of wet deposition analytes determined by IC are recalculated using the procedures outlined in Steps a and b.
   f. The pH and conductivity data are audited by proofing the manual entry of data into CLASS™ and by reviewing QC data.
   g. Wet deposition data for K^+ are audited by regenerating the linear calibration curve and determining the correlation coefficients.
   h. Wet deposition Na^+, Ca^{2+}, and Mg^{2+} data (analyzed by ICAP) are audited by regenerating the linear calibration curves and recalculating correlation coefficients for all analytes.

i. Wet deposition data for acidity are audited by proofing the manual entry of data into the CLASS™ system and recalculating acidity on every tenth sample.

2. Flow Verification Audit:

   a. The on/off dates and times for all filter packs in the chemistry database are compared to data recorded by site operators on SSRFs.

   b. For all site-weeks, valid hours, total available hours, and average flow values are redetermined from Level II validation flow data obtained from the DMC and compared with corresponding values in the chemistry database.

   c. Total sample volume and atmospheric concentration [micrograms per cubic meter ($\mu g/m^3$)] of each analyte are calculated and compared for all filter pack samples with the data in the final chemistry report for the quarter.

3. Filter Acceptance and Chain-of-Custody Audits:

   a. All acceptance test data for Teflon®, nylon, and Whatman filters are reviewed to ensure that only batches of filters which met the acceptance criteria are used for sample collection.

   b. Field logsheets for selected sites for the entire quarter are reviewed to determine completeness of the shipping and receiving dates for filter packs.

4. Precipitation Field Data Audits:

   a. Data reported on the PSRFs are compared to data in the chemistry database for all wet deposition sites.

   b. Precipitation amounts from the RG charts are recalculated for 20 percent of all samples. Collector efficiencies are recalculated when differences are discovered in the precipitation amounts. Audit samples are selected from those samples with collector efficiencies of either <80 percent or >120 percent.

   c. Weekly precipitation amounts are recalculated from the RG charts for the entire quarter for one wet deposition site and compared to corresponding values on the PSRFs.

5. QC Chart Audits:

   QC charts are reviewed to ensure that all batches and all analytes meet the established data quality criteria, or that appropriate corrective actions are implemented.

6. Life History Audits:

   The life history audit traces samples from a selected week within the quarter from media testing and preparation through chemical analysis to inclusion into the validated database. The format for this audit may vary from quarter to quarter. For example, it may not be necessary to audit each component of sample analysis every quarter.

2.2.4.3 External Audits

External QA was provided by Ogden. Ogden performed annual field, laboratory, and DMC audits. Two types of external QA reports were prepared by Ogden. Spot reports providing rapid feedback on sensor and system performance were submitted to QST within 72 hours of a site audit. Monthly audit reports from Ogden contained audit data from each site, details of problems encountered, and descriptions of recommended solutions.

2.2.4.4 Precision and Accuracy Objectives

Three separate measures of precision are produced for CDN data. The primary assessment of overall precision is made using collocated (i.e., duplicate) sets of equipment at selected sites. Direct field measurements and laboratory measurements are compared the same way. In addition, all laboratory measurements require two assessments of analytical precision: one to assess sample-to-sample precision within a single analytical data batch, and one to assess batch-to-batch precision. Batch-to-batch precision is estimated only for filter pack analyses. Precipitation samples undergo a series of analytical procedures for analysis of numerous parameters and are therefore not suitable for batch-to-batch replication.

The overall precision of meteorological variables and O_3 is assessed quarterly by calculating the difference between simultaneous measurements (i.e., hourly averages) taken by separate instruments at collocated sites. Collocated sites are selected to be representative of the observed range of pollutant concentrations and environmental conditions that exist within the network. The precision objectives for the CDN for field measurements are listed in Table 2-5.

The overall precision of atmospheric concentration and wet deposition data is assessed quarterly by calculating the relative percent difference (RPD) of values for simultaneous samples at collocated sites. Precision objectives for these variables are listed in Table 2-9.

The precision objectives listed in Tables 2-5 and 2-9 have been estimated from instrument specifications, EPA data, and QST experience with similar measurements. Approximately 10 percent of CDN sites were collocated in the past. Currently, only 5 percent of the network is collocated as adequate results on network precision were obtained during the earlier years. The current 5 percent collocation level provides sufficient information to assess whether precision estimates continue to meet CASTNet objectives.

Analytical precision within sample batches is assessed by calculating the RPD and percent recovery of CVSs run in that batch. CVSs are independently produced standards, which approximate the midpoint of the analytical range for an analyte and are run after every tenth environmental sample. Precision within a batch is also assessed by replicating 5 percent of the samples within a run. Samples to be replicated are selected randomly.

Analytical precision from batch to batch for dry deposition anions and NH_4^+ is estimated by analyzing selected samples in two separate batches. Five percent of each batch is selected at random and rerun in a subsequent batch. Although no precision objectives have been established for this analysis, comparisons provide a means of estimating the batch-to-batch analytical precision.

The accuracy of field measurements is determined by challenging instruments with standards that are traceable to the NIST. Continuing accuracy is verified during quarterly calibration by QST personnel and annual audits by an independent QA auditor. Accuracy objectives for field measurements are listed in Table 2-5.

The accuracy of laboratory measurements is determined by analyzing an independently prepared reference sample in each batch and calculating the percent recovery relative to the target (theoretical) value. The percent recovery must meet or exceed the acceptance criteria listed in Table 2-9. If possible, the reference should be traceable to NIST, be obtained directly from NIST (when available), or ordered from other laboratories. Unknown reference samples containing SO_4^{2-} and NO_3^- on filter media are also provided by the EPA Project QA Officer. Unknown reference samples provided by EPA are extracted using CDN procedures and analyzed at the beginning and end of each IC run.

2.2.4.5 Precision and Accuracy Results

Field Data

Precision statistics generated via collocated sampling efforts from 1987 through 1995 are presented in Table 2-10. The operational time periods for each collocated site that correspond to the precision values in Table 2-10 are presented in Table 2-11. Precision estimates in RPD for all meteorological parameters for all collocated sites ranged from -20.67 to 87.82 percent. Both of these values are for delta temperature and appear high due to differences at the low end of the Centigrade scale (0.13 versus 0.16°C, and 0.04 versus 0.02°C, respectively). The absolute RPDs for each parameter averaged for all collocated sites are presented in Table 2-12. Except for an RPD of 20.95 percent for delta temperature, all other RPDs are well within CASTNet criteria, ranging from 0.63 to 9.91 (wetness). Table 2-13 presents results of collocated sampling for the two sites collocated during 1994 as an example of results from a typical sampling year.

Results of the external performance audits conducted by Ogden are used as an estimate of accuracy. Table 2-14 lists by site the external audit results performed during 1994. Summary statistics of the external audit results for 1994 are presented in Table 2-15. Of 430 sensors audited, only 2.8 percent (12 sensors) failed to meet CASTNet accuracy criteria, and 2.6 percent (11 sensors) were within warning limits.

Except for the delta temperature and wetness sensors, the precision of the field instrumentation, as assessed by collocated sampling, is excellent. Results for delta temperature appear highly variable as the precision estimate of RPD magnifies the small differences at the low end of the Centigrade scale. If the precision acceptance criteria of ± 0.25°C (see Table 2-5) is directly applied to the differences between the collocated instrument values, then all collocated delta temperature sensors fall within the acceptance limits. Results for the wetness sensors, on the other hand, appear relatively variable due to the fact that the sensors are difficult to align with high precision within one hour of one another.

Accuracy of the field instrumentation as assessed by external audits is also excellent, indicating that the continuous O_3 and meteorological data are of the highest quality.

Laboratory Data

Filter Pack Samples

Precision results by site via collocated sampling for filter pack data from 1987 through 1995 are presented in Table 2-16 (see Table 2-11 for the corresponding operational time periods for each collocated site). Precision estimates in RPD for all analytes for all collocated sites ranged from -3.86 percent for SO_2 to 10.59 percent for NO_3^-. The absolute RPDs for each analyte averaged over all collocated sites (Table 2-17) ranged from 1.56 percent for SO_4^{2-} to 3.65 percent for NO_3^-. Table 2-18 presents results of collocated sampling for the two sites collocated during 1994 as an example of results from a typical sampling year, and Figures 2-10 and 2-11 display these results as scatterplots for SO_4^{2-}, SO_2, NO_3^-, and HNO_3.

Precision estimates obtained from analysis of CVS and replicate samples for 1994 (typical project year) and for the 1987 through 1995 period (total average project precision) are presented in Tables 2-19 and 2-20, respectively. Precision for the CVS samples is calculated as percent recoveries whereas precision for the replicate sampling is calculated as RPDs. Percent recoveries for both 1994 and the entire period for all analytes were within -1.54 percent of 100, and the RPDs for the replicate analyses for both time periods were between 1.21 percent for SO_4^{2-} (Teflon® filter) and 8.24 percent for NO_3^- (Whatman filter) in batch-to-batch replicates, and between 0.58 percent for SO_4^{2-} (Teflon® filter) and 3.73 percent for NO_3^- (Whatman filter) for in-run replicates. As might be expected, in-run replicates exhibited greater precision than batch-to-batch replicates. Replicate analysis results also yielded the highest standard deviations. This is due to analysis of samples with low-level concentrations near the detection limits where small differences in replicate versus original values are amplified. Since samples to be replicated are chosen randomly (i.e., "blind"), inclusion of low concentration samples could not be avoided.

Accuracy of the filter pack sample analyses is estimated by calculating the percent recoveries of NIST reference solutions. Accuracy estimates for 1994 and the 1987 to 1995 period are also presented in Tables 2-19 and 2-20, respectively. Percent recoveries for both time periods ranged from 98.47 percent for NO_3^- (Whatman filter) to 100.68 percent for SO_4^{2-} (nylon filter). In general, the precision and accuracy of the laboratory data are extremely high. The only notable exceptions where precision criteria were not met occurred for NO_3^- species during estimation of precision via collocated sampling. The NO_3^-, HNO_3, and total-NO_3^- precision

values for 1987 through 1995 for collocated Site 107/207 (Table 2-16) were out of the acceptance criteria of ±5 percent with values of 10.59, 7.90, and 8.38, respectively. It should be noted, however, that this site was collocated for only 18 months and was one of the first sites to be configured as such. The only other collocated site to exceed acceptance criteria was Site 153/253 for NO_3^- (7.61 RPD), another pioneer collocated site. Besides the fact that these sites exhibit two of the lowest average NO_3^- concentrations in the east with respect to other eastern collocated sites, the high RPDs may also be reflective of configurational problems at the sites rather than poor precision.

Precipitation Samples

Precision results by site via collocated sampling for wet deposition data from 1989 through 1995 (wet deposition sampling did not begin until 1989) are presented in Table 2-21 (see Table 2-22 for the corresponding operational time periods for each collocated site). Precision estimates in RPD for all analytes for both collocated sites ranged from -18.32 percent for ammonia (NH_3) to 9.82 percent for NH_4^+. The absolute RPDs for each analyte averaged over all collocated sites (Table 2-23) ranged from 0.30 percent for SO_4^{2-} to 14.07 percent for NH_4^+. Table 2-24 presents results of collocated sampling for the two sites collocated during 1994 as an example of results from a typical sampling year.

Precision estimates obtained from analysis of CVS and replicate samples for 1994 and for the 1989 through 1995 period are presented in Tables 2-25 and 2-26, respectively. Percent recoveries of CVS samples for both 1994 and the 1989 through 1995 period for all analytes were within ±4.83 percent of 100, and the RPDs for the replicate analyses for both time periods were between 0.22 and 5.15 percent. Unlike filter pack analyses, replicate analysis results did not necessarily exhibit higher standard deviations. Precipitation samples are replicated in sequence (i.e., replicate analyzed immediately after original sample) whereas filter pack replicates are analyzed at the end of a batch. There can be a difference of up to 3 hours between analysis of the original and replicate sample as well as up to 60 samples in between the replicate and original sample. The higher RPDs and standard deviations of the filter pack samples may simply be reflective of instrument drift and slight changes in the IC column integrity.

Accuracy of the precipitation sample analyses is estimated by calculating the percent recoveries of NIST reference solutions. Accuracy estimates for 1994 and the 1989 to 1995 period are also presented in Tables 2-25 and 2-26, respectively. Percent recoveries for both time periods ranged from 95.84 percent for Na^+ to 105.35 percent for pH. Unknown reference samples prepared by High Purity Standards are also analyzed along with the CDN precipitation samples as an extra internal check. The percent recoveries of these samples are also presented in Tables 2-25 and 2-26.

Chapter 3
Results and Discussion

3.1 Overview

Air quality measurements collected since the commencement of the NDDN in 1987 through the year 1995 are presented and analyzed in this chapter. The scope of the analysis has been limited generally to graphical and tabular presentation and straightforward statistical analyses, which do not account for the year-to-year variations in meteorology or for quantified modeled uncertainties. More detailed and interpretative studies will be presented elsewhere.

The results from Chapter 2 demonstrate conclusively that the observed changes in concentrations shown in the figures and tables in this chapter are real and not the result of modifications to field and analytical protocols or of data imprecision or inaccuracy. The few changes in sampling and analytical procedures have been assessed and have been shown to have had a positive or neutral effect on data quality. The CASTNet QA/QC program has demonstrated the accuracy and precision of the measurements. Concentration reductions are the result of changes in emissions and of meteorological fluctuations, not of changes in the network.

Concentrations measured on the CASTNet filter packs are presented first. Concentration data are given in terms of annual and quarterly averages, summer (June through August) and winter (December through February) levels and various scattergrams and time series. Linear regressions of annual, summer and winter values versus year are shown to ascertain any statistically significant trends in concentrations.

The multilayer model (MLM) used to calculate deposition velocities from meteorological measurements and various land-use data is described. Example calculations in terms of time series of weekly average deposition velocities are presented for several sites.

Dry depositions (fluxes) are calculated as the product of weekly average deposition velocities and concentrations. Annual average depositions and time series of weekly deposition rates are presented. Depositions are compared to concentrations. The deposition data are analyzed for trends.

Precipitation chemistry and precipitation rates are measured at 21 CASTNet sites (18 eastern). Pollutant concentrations in precipitation and wet deposition rates are calculated. These data are combined with data from certain NADP sites located near CASTNet sites to assemble tables and maps of annual, seasonal, and quarterly average depositions and concentrations. These data are analyzed for trends.

Dry and wet deposition data are combined to estimate total deposition of sulfur and nitrogen species. Annual and seasonal averages are presented by year and by region. Total deposition rates are analyzed for trends.

O_3 measurements are then presented and discussed. The O_3 data are used to provide estimates of various exposure statistics and to assess compliance with current and proposed air quality standards. The data are also used to analyze the effects of terrain and other site characteristics on O_3 concentrations.

The MADPro is then discussed. Concentrations in rain, cloudwater, and ambient air are compared.

Data from the CASTNet Visibility Network are presented. The section begins with a description of the network, instrumentation, and operations. An initial analysis of the visibility-related air quality measurements is presented. The year 1994 was selected for the analyses and presentations. Annual concentrations of fine particles and their chemical constituents are shown, and seasonal variability is also discussed. Time series of 24-hour average fine particle concentrations and the chemical constituents are presented. Relationships between fine particle concentrations and SO_4^{2-} concentrations and between atmospheric light scattering coefficient (B_{scat}) and fine particles and SO_4^{2-} are discussed. Finally, photographs of scenic vistas at the Arendtsville site are contrasted for high and low SO_4^{2-} days.

Chapter 3 also provides example results from other studies sponsored by CASTNet. Brief descriptions are given of the mobile monitoring system used to measure directly dry deposition fluxes and comparisons between denuder and filter pack measurements.

3.2 Air Chemistry and Dry Deposition

The emphasis of CASTNet has been the measurement of ambient concentrations of sulfur species (SO_2 and SO_4^{2-}), nitrogen species (HNO_3, NO_3^-, and total NO_3^-), NH_4^+, and O_3, which is a product of the photochemical reactions among NO_x and reactive organics. Precursor emissions are transported by the wind, mixed by atmospheric turbulence, undergo dry and wet deposition, and are transformed to other species by chemical processes. A simple, linear model of the change in SO_2 and SO_4^{2-} concentrations is shown in Equations 3-1 and 3-2.

$$\frac{\partial C_2}{\partial t} = -u\frac{\partial C_2}{\partial x} - \frac{\partial}{\partial z}\left(K_z\frac{\partial C_2}{\partial z}\right) - k_{D_2}C_2 - k_t C_2 - kw_2 C_2 + Q_2 \qquad (3\text{-}1)$$

$$\frac{\partial C_4}{\partial t} = -u\frac{\partial C_4}{\partial x} - \frac{\partial}{\partial z}\left(K_z\frac{\partial C_4}{\partial t}\right) - k_{D_4}C_4 - kw_4 C_4 + \frac{3}{2}k_t C_2 \qquad (3\text{-}2)$$

The two equations represent the various atmospheric processes that produce changes in SO_2 and SO_4^{2-}. SO_2 is represented by C_2 and SO_4^{2-} by C_4 in the two equations. The first two terms represent advection and turbulent mixing. The terms $k_{D_2}C_2$ and $k_{D_4}C_4$ represent the dry deposition of the gas SO_2 and aerosol SO_4^{2-}. The two terms kw_2C_2 and kw_4C_4 represent the scavenging of SO_2 and SO_4^{2-} by precipitation. The term k_tC_2 represents the conversion of SO_2 into SO_4^{2-}. It represents a loss of SO_2 in Equation 3-1 and a gain of SO_4^{2-} in Equation 3-2. The Q term represents emissions. The concentration terms are three-dimensional. The other parameters are a function of both space and time. The production of HNO_3 and NO_3^- from NO_x emissions can be represented by similar, but more complicated (i.e., with nonlinear chemical reactions), equations.

Equations 3-1 and 3-2 provide a simple framework in which to consider the results presented in this chapter. For example, SO_2 and SO_4^{2-} are lowered by dry deposition processes (the third terms in the two equations) and by precipitation scavenging (the fourth terms). The terms k_{D_2} and k_{D_4} are related to deposition velocities (discussed in Section 3.2.2) and vary with space and time (e.g., seasonally and diurnally). The production of SO_4^{2-} from SO_2 is simulated as a linear transformation process. In reality, the transformation processes are nonlinear and are controlled by complex photochemical processes. Sophisticated models like the Regional Acid Deposition

Model (RADM) (Dennis *et al.*, 1993) simulate the highly nonlinear chemical transformations. However, the k_t term captures the essence of the production of SO_4^{2-} in that SO_4^{2-} is produced directly from SO_2 and the transformation varies with space and time (e.g., higher transformation associated with summertime photochemical processes).

Concentrations are measured directly throughout the eastern and western networks. Dry depositions are estimated as the product of concentrations and modeled dry deposition velocities. Concentrations and dry depositions are discussed in detail in this section of the report. Wet deposition is measured at 21 CASTNet sites. Wet depositions are discussed in Section 3.3. The CASTNet wet deposition measurements are combined with wet deposition data from NADP to provide geographic coverage of the eastern subregions. The dry and wet deposition data are summed in Section 3.4 to obtain information on total deposition. O_3 concentrations are discussed separately in Section 3.5.

3.2.1 Concentrations

3.2.1.1 Six-Year and Annual Average Concentrations

Sulfate

Figure 3-1 shows annual average SO_4^{2-} concentrations averaged over the 6-year period 1989 to 1994. This period was selected because of its extensive and relatively complete data record. Figure 3-2 shows SO_2 emissions (EPA, 1996) for the same period. The map of concentrations represents a regional-average, 6-year exposure to SO_4^{2-} that is produced by the SO_2 emissions, remembering that the CASTNet measurements were taken to characterize regional, rural conditions. The monitoring sites were situated to avoid individual point sources and groups of sources and to represent regional air quality.

Six-year average concentrations above 6.0 $\mu g/m^3$ were observed from southwestern Indiana to northern Alabama across central Pennsylvania, reflecting the geographic distribution of large emitters along the Ohio river. The highest value of 6.7 $\mu g/m^3$ was measured at several sites. Most of the eastern portion of CASTNet measured concentrations above 4.0 $\mu g/m^3$, with a sharp decrease in New York and New England.

The measurements at the western sites ranged from 1.4 to 0.7 $\mu g/m^3$.

To assess variability in annual averages, maps of annual SO_4^{2-} concentrations for the years 1989, 1992, and 1994 are presented in Figures 3-3 through 3-5. Similar concentration patterns were observed in the 3 years with the highest measured values in 1989. Only a few values above 6.0 $\mu g/m^3$ were measured in 1992. A larger region and more sites with values above 6.0 $\mu g/m^3$ are shown on the 1994 map. A discussion of geographic averages and trends in SO_4^{2-} is provided later in Section 3.2.5.

Sulfur Dioxide

Average SO_2 concentrations from 1989 to 1994 are given in Figure 3-6. A broad area of values above 10 $\mu g/m^3$ extends from southern Illinois to western New York, again reflecting the distribution of SO_2 sources in Figure 3-2. Annual averages for 1989, 1992, and 1994 are given in Figures 3-7, 3-8, and 3-9, respectively. Fairly similar patterns of higher SO_2 levels were observed from year-to-year, although the number of sites with high levels and the magnitude of the peak observations decreased from 1989 to 1994.

Nitrate

Figure 3-10 shows the 1989 to 1994 average NO_3^- levels for the CASTNet. Figure 3-11 shows NO_x emissions for the same period. Six-year average NO_3^- concentrations are more variable spatially than SO_4^{2-} with the highest levels measured in the Midwest. The pattern of observed NO_3^- is not as well correlated with the distribution of NO_x emissions as was SO_2 and SO_4^{2-}. For example, NO_x emissions in the Southeast are about the same magnitude as in the Midwest, yet NO_3^- levels are significantly lower. In short, the highest NO_3^- were observed in the agricultural area of the Midwest. This suggests two potential mechanisms for NO_3^- formation, including the gas-phase reaction between HNO_3 and NH_3 and gas-particle reaction of HNO_3 with soil particles. Although both reactions are likely in agricultural areas, the apparent spatial correlation between NH_4^+ and NO_3^- levels (see Section 3.2.1.4) provides evidence that the first mechanism may be more important.

Six-year average NO_3^- concentrations show little variability across the western sites. Measured averages are all below 0.6 $\mu g/m^3$.

Annual average NO_3^- values for 1989, 1992, and 1994 are illustrated in Figures 3-12 through 3-14, respectively. Nitrate values show extensive geographic variability but little yearly change.

Ammonium

Six-year average NH_4^+ concentrations are shown in Figure 3-15. In general, higher concentrations were detected at agricultural sites, rather than forested sites. Measured NH_4^+ concentrations are less than or equal to 0.5 $\mu g/m^3$ throughout the western network.

Annual average levels of NH_4^+ for 1989, 1992, and 1994 are given in Figures 3-16 through 3-18, respectively. The annual patterns are similar, and higher concentrations were generally measured in 1989.

Nitric Acid

HNO_3 concentrations averaged from 1989 to 1994 are shown in Figure 3-19. In general, the data show little spatial variability except in the northern and southern extremes of CASTNet and in the Appalachians. The effects of complex terrain on site exposure, local photochemistry, and dry deposition could explain some of the spatial variability. This topic is explored later in this chapter. Concentrations observed across the western sites range from 0.9 to 0.3 $\mu g/m^3$.

Annual HNO_3 levels for 1989, 1992, and 1994 are given in Figures 3-20, 3-21, and 3-22, respectively. The concentration patterns are similar from year to year and to the 6-year average distribution. Lower concentrations were measured in 1992. The highest annual average was routinely measured in southeastern Pennsylvania.

Total Nitrate

The 6-year composite map for total NO_3^- is shown in Figure 3-23. The data show considerable spatial variability among the sites in the eastern network. Total NO_3^- levels are influenced by complex terrain effects at the higher elevation sites and by the availability of particulate NO_3^- in agricultural areas. The higher values were observed in the Midwest and eastern Pennsylvania. Values at western sites range from 1.2 to 0.5 $\mu g/m^3$. Annual maps of total NO_3^- for 1989, 1992, and 1994 are shown in Figures 3-24 through 3-26, respectively. Annual patterns are similar from year to year. The highest values were measured in 1989.

Summary of Annual Averages

As discussed earlier, one of the objectives of the CASTNet is to detect trends in air quality measures in response to changes in emissions. Tables 3-1, 3-2, and 3-3 list annual average concentrations for six air quality parameters (two each table) for the years 1987 through 1995. Annual levels are provided for each CASTNet subregion and for all eastern and western sites combined. A site had to have data for 26 weeks during a year to be included in this table.

The data for the eastern sites combined show a 23-percent reduction in SO_4^{2-} and a 43-percent reduction in SO_2 between 1989 and 1995 annual concentrations. These values do not account for the variations in concentrations between 1989 and 1995. Changes in sulfur species are more pronounced in the four northern subregions and smaller, but still substantial, in the two southern subregions. There is no apparent trend in the data from the western sites. The eastern data indicate about 70 percent of ambient sulfur is in the form of SO_2. Throughout the western network SO_2 represents about 55 percent of the ambient sulfur.

As shown in Table 3-3, HNO_3 and total NO_3^- concentrations averaged over the eastern sites show little change over the monitoring period, with perhaps a 5-percent reduction in total NO_3^-. HNO3 concentrations show a downward trend in three of the subregions.

Concentrations averaged over the western network are all less than 1.0 $\mu g/m^3$. There is some evidence of a reduction in total NO_3^- with a decrease to 0.69 $\mu g/m^3$ from the 1989 average of 0.85 $\mu g/m^3$. Nitric acid contributes about 65 percent of ambient nitrogen throughout the network.

3.2.1.2 Quarterly Average Concentrations

Time series of quarterly average concentrations of SO_2 and SO_4^{2-} are given in Figures 3-27 and 3-28, respectively, for Sites 109 (Woodstock, NH) and 120 (Horton Station, VA). Despite large concentration differences, seasonal patterns are similar between sites and between years. SO_2 levels are the highest in the winter and fall and drop off markedly in spring and summer. Sulfate values rise during the spring, peak in summer and reach minimum levels in fall and winter. SO_2 emissions are typically high in the winter and summer, reflecting heating and air conditioning demands. The photochemical production of SO_4^{2-} in summer corresponds to a time with high emissions. With little photochemical activity in the cold months SO_2 emissions produce the highest ambient SO_2 concentrations.

3.2.1.3 Summer and Winter Averages

To illustrate further seasonal behavior, Figures 3-29 through 3-40 present time series of summer (June through August) and winter (December through February) averages for the six filter pack measurements (i.e., SO_4^{2-}, SO_2, NO_3^-, NH_4^+, HNO_3, total NO_3^-) for five eastern and three western sites. Figures 3-29 through 3-34 show the summer and winter averages for the eastern sites. Similarly, Figures 3-35 through 3-40 show the summer and winter averages for the western sites. The 1989 winter averages represent the period December 1988 through February 1989 and so forth for subsequent years.

Summer SO_4^{2-} concentrations show considerable year-to-year variability (i.e., typically 20 percent or more) throughout the eastern network. Summer SO_4^{2-} at the western sites is less variable and fairly low in concentration. Winter SO_4^{2-} shows little annual change throughout the east and is typically less than 3.0 or 4.0 $\mu g/m^3$. Winter SO_4^{2-} in the west is typically less than 1.0 $\mu g/m^3$. During four of the seven years, SO_4^{2-} levels are higher in the winter than the summer at Site 168 (Glacier NP).

Winter SO_2 levels are about a factor of 2.0 higher than summer levels and exhibit considerable annual variability among the eastern sites. The Woodstock, NH site (109) and the Sumatra, FL site were exceptions and measured very low SO_2 concentrations with almost no year-to-year change. With the exception of Glacier NP, MT, SO_2 levels were higher in the winter at the western sites.

The year-to-year variations in measured summer and winter average SO_4^{2-} and SO_2 concentrations are consistent with regional (e.g., RADM) modeling studies which simulate 20- or 30-percent changes from year to year. Even point source modeling studies, assuming constant emissions, result in 20- to 30-percent variability at a model receptor location over a 5-year simulation period because of fluctuations in meteorological conditions.

Ammonium and HNO_3 concentrations are generally higher in the summer throughout CASTNet. Woodstock, NH, and Sumatra, FL, are exceptions in that there is little difference between summer and winter levels. Similarly, HNO_3 measured at Glacier NP, MT, shows little summer-winter variability.

Total NO_3^- levels do not vary much between winter and summer at the eastern sites. Observed summer total NO_3^- concentrations are higher in summer in Arizona and Wyoming, but lower at Glacier NP, MT.

3.2.1.4 Ammonium Versus Sulfate

Data for the CDN sites suggest regional variability in aerosol speciation as well as concentration. This is illustrated in Figure 3-41, which shows the relationship between NH_4^+ and SO_4^{2-} (molar basis) for each CDN site using annual average concentrations for 1991 as an example. Similar relationships were observed for other years. Solid and dashed lines are also plotted in this figure to depict 1:1 and 2:1 ratios of NH_4^+ to SO_4^{2-}, respectively. The 2:1 line represents completely neutralized SO_4^{2-}, and the 1:1 line represents 50-percent neutralization of SO_4^{2-}, assuming that only NH_4^+ and SO_4^{2-} are present in the aerosol phase. Other aerosol species are undoubtedly present and, therefore, ratios represent only approximate levels of neutralization.

Results show that the majority of eastern sites fall between the 50-percent and 100-percent neutralization lines and that the western sites scatter around the 100-percent neutralization line. Inspection of Figure 3-41 also shows a small number of eastern sites on or above the 100-percent neutralization line and a small number of sites only slightly above the 50-percent neutralization line. The highest NH_4^+:SO_4^{2-} ratios all correspond to agricultural sites in the midwest and upper midwest. The lowest ratios of NH_4^+:SO_4^{2-}, in contrast, all correspond to sites in predominately forested areas of the southeast and northeast.

Although filter pack data cannot be used to quantify aerosol acidity, these results suggest broad qualitative differences in aerosol acidity. For agricultural sites in general, there appears to be sufficient NH_4^+ to completely neutralize SO_4^{2-}. For forested sites at significant distances from agricultural activity, observed SO_4^{2-} must be balanced by other cations in addition to NH_4^+. The metal cations Na^+, K^+, Ca^{2+}, and Mg^{2+} were measured in CDN filter pack samples during 1989 (ESE, 1990c). Results showed that Na^+, K^+, Ca^{2+}, and Mg^{2+} were minor aerosol constituents at all sites except those in the midwest or near the coast (Sites 104, 116, and 156). On the whole, these data show that aerosol composition varies from region to region and suggest that aerosol acidity may be greater at predominantly forested sites then at predominantly agricultural sites.

3.2.1.5 Trend Analysis

The 1970 Clean Air Act (CAA), the Amendments of 1977, and the 1990 Amendments have produced reductions in SO_2 and NO_x emissions over the last two decades. Specifically, the 1990 Act called for a 10-million tons per year reduction in SO_2 emissions relative to 1980 emissions. EPA (1997) has estimated that SO_2 emissions were actually reduced by 13 percent in 1995 as the result of CAA requirements. EPA has also calculated a 22-percent reduction in nationwide SO_2 emissions over the period 1989 to 1995, a 25-percent reduction in SO_2 emissions in the eastern United States over the same period, and a 24-percent reduction in electric utility SO_2 emissions. Without taking into account year-to-year variability, CASTNet data from the eastern sites show a 43-percent reduction in SO_2 concentrations, a 23-percent reduction in SO_4^{2-} levels, and a 38-percent reduction in ambient sulfur between 1989 and 1995 (Table 3-1). Figures 3-42 and 3-43 show the measured percent reduction in annual concentrations of SO_2 and SO_4^{2-}, respectively, from 1989 through 1995. Reductions are provided for individual sites and for subregional averages. The highest percent reductions for both SO_2 and SO_4^{2-} were observed for the upper midwest and upper northeast subregions. Reductions were observed for all subregions.

CASTNet has measured significant reductions in concentrations of sulfur species. Are those reductions related to changes in SO_2 emissions or natural meteorological variability, or both? Although detailed statistical analyses are beyond the scope of this project, a few analyses have been performed to address the question. EPA (1997) has started detailed analyses of the relationships between emission changes and air quality and has developed nonlinear statistical models to detect trends in ambient sulfur and nitrogen species.

The initial statistical analyses presented herein are simple linear regressions. Although they do not differentiate between emission changes and meteorological fluctuations, linear regressions can assess the statistical significance of the observed trends, whatever their cause. Figure 3-44 shows linear regressions based on annual average SO_2 concentrations versus year for the entire eastern network. The figure shows statistically significant reductions in SO_2 averages at better than 95-percent confidence ($p \leq 0.05$). Similarly, linear regressions for annual SO_4^{2-} levels are shown in Figure 3-45. The results show statistically significant reductions in SO_4^{2-} since 1989.

Linear regressions were also calculated for the six eastern subregions and for the western data. Calculations were made for annual, summer, and winter average concentrations of SO_2 and SO_4^{2-} (see Tables 3-4 and 3-5). The reductions in annual SO_2 are considered statistically significant for all six eastern subregions. The annual data for the western network did not show a statistically significant trend. The regressions based on the summer average SO_2 concentrations show statistically significant reductions for five subregions, all except the southern periphery and the west. The reductions in winter SO_2 are considered statistically significant for four of the seven subregions.

For SO_4^{2-}, the reductions are considered significant for all seven subregions on an annual basis. The summer regressions show statistically significant reductions for five subregions and inconclusive results for northeast and midwest, although the p-values for these two regions are only slightly above 0.05, the value indicative of results at the 95-percent confidence level. The reductions in winter are considered statistically significant for two subregions.

Linear regressions were also performed on annual average HNO_3, NO_3^-, and total NO_3^- concentrations collected from 1987 through 1995. The results for all eastern sites combined are shown in Figures 3-46, 3-47, and 3-48. The results show a slight reduction in HNO_3 levels which is considered statistically significant. No significant trends are shown for NO_3^- and for total NO_3^-.

3.2.1.6 SURE Data

The analysis of trends for SO_4^{2-} concentrations can be extended by incorporating measurements taken in 1977 and 1978 during the Sulfate Regional Experiment (SURE) (Mueller *et al.*, 1983). Schreffler and Barnes (1996) recently used the SURE data and measurements from the Acid-MODES/OEN Network (Heisler *et al.*, 1992) to demonstrate a statistically significant reduction in SO_4^{2-} over the period 1978 to 1989.

Table 3-6, which was adapted from the Schreffler and Barnes (1996) paper, shows 1978 annual average SO_4^{2-} concentrations taken from the SURE Class I Network. The table also lists the five CASTNet sites that are located nearest the SURE stations. Figure 3-49 shows linear regression plots for Sites 144, 114, 140, 133, and 120 using the SURE and CASTNet data. The analysis shows average percent reductions in annual SO_4^{2-} over the period 1978 to 1995 from 35 to

50 percent. The results are statistically significant at the 99-percent confidence level for all five sites.

3.2.1.7 Summary of Trends in Concentrations

The CASTNet measurements show statistically significant reductions in SO_2, SO_4^{2-}, and HNO_3 concentrations averaged over all eastern sites. SO_2 concentrations show significant reductions in summer and winter seasons, even though concentrations are much higher in winter. The downward trends have been measured consistently across the eastern network, except for the subregion called the southern periphery. The sites in this region are less influenced by source groups and, hence, less influenced by change in SO_2 emissions. No trend is evident in the western data.

The downward trend in SO_4^{2-} has been observed consistently across all eastern sites. The decline in summer average SO_4^{2-} levels explains the decline in annual averages. Sulfate peaks in the summer because of active photochemical reactions that transform SO_2 into SO_4^{2-}. Extending the trend analysis by including the 1978 SURE measurements reinforces the demonstration of a significant downward trend in SO_4^{2-}.

The reduction in HNO_3 concentrations results from the decline in summer averages. The downward trend is observed in all of the subregions, except for the southern periphery and the west. No trends are observed in annual concentrations of NO_3^- and total NO_3^- averaged over the eastern and western networks.

3.2.2 Calculation of Deposition Velocities

CASTNet was designed to use meteorological measurements and information on land use, vegetation, and surface conditions to calculate dry deposition velocities for each filter pack measurement and O_3. The meteorological and O_3 data are recorded continuously and archived as hourly averages. The filter pack measurements give weekly concentrations. Site operators survey major plant species and land use within 1 km of each monitoring station. They also record the presence of dew, frost and snow. Weekly vegetation information is also recorded. The LAI was surveyed at each site during periods of maximum leaf out during the summers of 1991 and 1992.

3.2.2.1 Deposition Model

The network design was based on the assumption that dry deposition or flux could be estimated as the linear product of ambient concentration (C) and V_d:

$$Flux = \overline{C} * \overline{V_d} \tag{3-3}$$

where the overbars indicate an average over a suitable time period (Chamberlain and Chadwick, 1953).

The influence of meteorological conditions, vegetation, and chemistry is simulated by V_d. Dry deposition processes are modeled as resistances to deposition (Hicks *et al.*, 1985):

$$R = R_a + R_b + R_c = 1/V_d \tag{3-4}$$

R_a, the aerodynamic resistance, is inversely proportional to the atmosphere's ability to transfer material downward from the planetary boundary layer to the surface layer by turbulent processes. R_b is the boundary layer resistance to vertical transport (molecular diffusion) through a shallow (approximately 1 millimeter) nonturbulent layer of air in direct contact with the surface. R_b depends on the aerodynamics of the surface and the diffusivity of the pollutant being deposited. R_c, the canopy or surface uptake resistance, contains several terms (represented as parallel resistances) that account for the direct uptake/absorption of the pollutant by leaves, soil, other biological receptors within and below the canopy, and other surfaces such as rock and water. R_c contains parameterizations for vegetation type and density, solar radiation penetration of the canopy and wetness of the surface. R_c is difficult to treat theoretically, and the system of equations for estimating R_c is normally empirically adjusted based on direct observation of dry fluxes. Figure 3-50 illustrates the resistance model of dry deposition.

For pollutant species with low solubility or reactivity, such as O_3 and SO_2, the controlling component of R_c is the stomatal resistance, which has large diurnal and seasonal variability. For highly reactive species such as HNO_3, R_c is generally small, regardless of season or canopy type, and R_a and R_b control V_d. Deposition of the particle species SO_4^{2-} and NO_3^- is primarily governed by turbulent processes and is represented in the model as a function of R_a.

Using this physical and mathematical framework, two dry deposition models (Big Leaf and MLM) have been used to calculate dry deposition for CASTNet. Both models were developed by NOAA Atmospheric Transport and Diffusion Division, Oak Ridge, TN. The Big Leaf model (Hicks *et al.*, 1985) treats the vegetation canopy as a one-dimensional surface. Big Leaf model results, aggregated to seasonal and annual averages for 1991, have been reported by Clarke and Edgerton (1993). The MLM is a variation of the Big Leaf model wherein similar calculations are applied through a 20-layer canopy in which model parameters are modified by the redistribution of heat, momentum, and pollutants (see Figure 3-50). The MLM also accounts for water stress on the vegetation and deposition to snow surfaces. Additionally, several parameters (e.g., soil resistance) have been modified in the MLM from those used in the Big Leaf model. While the MLM is a significant technical improvement over the Big Leaf model, seasonal and annual fluxes calculated by the two models do not differ greatly. Dry deposition calculations for the CASTNet sites (and the results reported here) are currently made using a version of the MLM (Meyers *et al.*, 1991).

The MLM requires the following input data: wind speed, wind direction, sigma theta, temperature, relative humidity, solar radiation, surface wetness, LAI, vegetative species, and percent green leaf-out.

The meteorological variables used to determine R_a, R_b, and R_c are obtained from the 10-m meteorological tower at each of the sites, normally located in a clearing over grass or another low vegetative surface. Data on vegetative species and percent green leafout are obtained from site surveys and observations by the site operator. LAI measurements were taken during 1991 and 1992 at times of summer maximum. LAI values that are used in the MLM are extrapolated from the 1991 and 1992 measurements using percent leafout observations. The resistance terms (R_a, R_b, and R_c) are calculated for each chemical species and major vegetation/surface type every hour. The V_d for a site is then calculated as the area-weighted V_d over vegetation types within 1.0 km of the site. Hourly V_d values are then averaged over a week and multiplied by the weekly integrated concentrations to produce weekly fluxes of HNO_3, SO_4^{2-}, NO_3^-, NH_4^+ and SO_2. O_3 flux is calculated using hourly O_3 measurements and hourly V_d values. Weekly flux calculations are considered valid if more than 70 percent of hourly V_d values are available for

that week. Weekly values were aggregated to seasonal averages if 10 of 13 weeks are valid. Seasonal averages are aggregated to annual only if all four seasons are valid.

3.2.2.2 Model Uncertainties

Uncertainties in MLM calculations can be considered in the context of the model formulation, input errors, and representativeness. The MLM itself is an imperfect representation of the large number of complex atmospheric processes that the model simulates. Consequently, the MLM calculations will never be able to match perfectly observed deposition velocities. Instrument errors and incomplete or inaccurate characterization of other input data (e.g., percent green leafout or LAI) produce uncertainties in model calculations. Extrapolation of deposition velocities calculated for specific CASTNet sites to larger regions may result in additional uncertainties.

Some MLM uncertainties are discussed briefly in this section to provide context to the calculated deposition velocities. EPA investigators (Clarke *et al.*, 1997) are currently evaluating the MLM in considerable detail. Results of these evaluations, sensitivity studies and statistical studies will be published elsewhere.

The MLM formulation is based on the assumption that covariance between C and V_d is zero over the appropriate sampling time (i.e., the right-hand term in the following equation is zero):

$$Flux = \overline{V_d} * \overline{C} + \overline{V_d' * C'} \qquad (3\text{-}5)$$

where the overbar indicates a weekly or hourly average.

The first term on the right-hand side is the product of the weekly average V_d and C (i.e., weekly flux, as calculated in the CASTNet). The second term on the right-hand side represents the covariance (correlation) between hourly concentrations and hourly deposition velocities. This term was assumed to be small, and thus ignored, in the formulation of the dry deposition model. Depending on its sign, the correlation may increase or decrease flux. There is evidence that the correlation between V_d and C may be large and positive under certain conditions. Meyers and Yuen (1987), using fall and winter data for a forested site near Oak Ridge, TN, found that the product of weekly average SO_2 and weekly average V_d provided a reasonable

estimate of flux relative to that calculated using hourly concentration and hourly V_d. In contrast, Matt and Meyers (1993) suggest the correlation term could be as large as 40 percent for SO_2 during the summer months at the same site. The MLM may, therefore, underestimate annual SO_2 fluxes at Oak Ridge by about 20 percent, considering the winter and summer results together.

The potential effect of the covariance term on the CASTNet dry deposition calculations specifically was assessed through an analysis of CASTNet data collected over a 21-month period from 1987 to 1989 when the network collected weekly integrated filter packs for separate daytime and nighttime periods. Fluxes were calculated as:

$$Flux1 = V_d(day) * C(day) + V_d(night) * C(night) \quad (3\text{-}6)$$

$$Flux2 = V_d(week) * C(week) \quad (3\text{-}7)$$

The ratio Flux2/Flux1 was calculated for each week of available data, and averages and standard deviations were calculated by species and month (see Clarke and Edgerton, 1993, for additional details). For SO_2 and HNO_3, calculating flux by Equation 3-7 (CASTNet approach) resulted in underestimation of the flux relative to Equation 3-6. The underestimate, averaged over the network, is about 5 to 15 percent (winter-summer range) for SO_2 and 5 to 20 percent for HNO_3.

As part of CASTNet, EPA has sponsored a program to measure directly dry deposition fluxes at selected sites (see Section 3.9 of this report). Field studies have been completed in eight locations since 1994. The data from these field studies provide a mechanism for the direct evaluation of the MLM simulations. Perhaps the most comprehensive databases for evaluating the MLM are available from field experiments at Bondville, IL (Site 130) during the summer and fall of 1994, at Sand Mountain, AL (Site 152) during the late spring of 1995, and at Keysburg, KY (near Nashville) during the summer and fall of 1995. An example evaluation is shown in Figure 3-51 which provides a comparison of MLM simulations and field measurements of V_d for O_3 at Bondville and Keysburg. The comparison shows that MLM underestimates V_d. In general, the MLM tended to underestimate V_d, especially during foliated, summertime conditions.

Apart from the uncertainties discussed previously, there can be significant spatial variability in dry deposition. The V_d reported for the CASTNet are areal averages representative of a 1-km radius surrounding the CASTNet site. Dry deposition may vary spatially due to variability in concentration and V_d. To minimize these effects, site-selection criteria emphasized uniform terrain and vegetation, as well as large distances from sources of pollutants. These siting criteria, however, cannot always be achieved.

Data from a site in southwestern North Carolina provide an interesting example of spatial variability in both concentration and V_d. The Coweeta, NC site (Site 137) is located in a valley about 300 m below and within 1,000 m of a satellite site, specifically located to study the effects of terrain on dry deposition. Concentration measurements for SO_4^{2-}, SO_2, and HNO_3 from the ridge site between June and December 1991 average 1.3, 2.6, and 2.5 times higher, respectively, than for the valley site. It is believed that these differences are primarily due to deposition under a shallow boundary layer characteristic of the valley site. Deposition velocity for the ridge-top site averaged 1.1, 1.2, and 1.7 times higher for SO_4^{2-}, SO_2, and HNO_3, respectively, than at the valley site, reflecting the higher levels of turbulence normally observed at higher elevations. Using the product of concentration ratios and V_d ratios as a first approximation of flux ratios, fluxes are about 1.4, 2.9, and 4.4 times higher at the ridge site for SO_4^{2-}, SO_2, and HNO_3, respectively. Although this may be an extreme example, it shows that the scale of representativeness of a site may be quite short, especially in areas of complex terrain.

A concept of MLM uncertainty is evolving based on the comparisons of modeled V_d for O_3 and SO_2 with the direct measurements, other studies reported in the literature, and the various uncertainty analyses. The MLM results tend to underestimate observed deposition velocities for SO_2 and O_3, especially daytime values during the periods of plant growth. The uncertainty is higher for periods of rapid plant growth. The results for HNO_3 and aerosols suggest that the uncertainty is higher because of the variability in windspeed and sigma theta.

Extrapolation of deposition velocities calculated for a specific CASTNet site to other locations should be done with caution, especially in areas of complex terrain.

3.2.2.3 Modeled Deposition Velocities

Annual average deposition velocities for SO_2 and HNO_3 are given by subregion in Table 3-7, and for O_3 and aerosols (SO_4^{2-}, NO_3^-, and NH_4^+) in Table 3-8. V_d for SO_2 is typically about 0.32 centimeters/second (cm/sec). The variability among subregions and from year-to-year is about 15 to 20 percent. The deposition velocity for HNO_3 averages about 1.7 cm/sec for the eastern sites and about 2.3 cm/sec for the western network. The annual and subregional variability is about 50 percent. The V_d for O_3 averages about 0.17 cm/sec throughout the eastern network and about 0.12 cm/sec in the west. The deposition velocity for particles is about 0.1 cm/sec for the eastern sites and about 0.16 cm/sec for the west.

The weekly variability of SO_2 V_d is shown for four sites for 1994 in Figure 3-52. The four sites represent a range in land-use characteristics in West Virginia, Virginia, Ohio, and Illinois. The West Virginia site is in forested, complex terrain. The Virginia site is a forested mountaintop site. The site at Oxford, Ohio is located at Miami University, 50 km northwest of Cincinnati. The site is characterized as rolling, agricultural. The Illinois site is a flat terrain site in the corn belt. The deposition velocities in Figure 3-52 show about a factor of 2.0 increase from the winter to the 3-month period of June to August. The mountaintop site shows the highest values which are slightly higher than the two rolling terrain sites. The flat terrain site experiences the lowest deposition velocities.

The deposition velocities for HNO_3 shown in Figure 3-53 show somewhat less of a winter-summer contrast than for SO_2. The weekly variability is greater; and the mountaintop site experiences the highest velocities although only during the fall are the values significantly higher than the Ohio site. Again, the flat terrain site in Illinois experiences the lowest deposition velocities.

Figure 3-54 illustrates deposition velocities for particles for the four sites. The data suggest peak velocities in the late spring and fall. The highest values are simulated for the rolling agricultural site in Ohio and the lowest values for the complex terrain site in West Virginia. Weekly variability is as high as a factor of 2.0.

The O_3 deposition velocities (Figure 3-55) show a strong summertime peak with more than a 400-percent increase over winter values. The flat terrain site in Illinois shows the lowest

values. There is little weekly variability other than the sharp gradients in the spring and fall. The distributions are virtually flat from November through March.

3.2.3 Dry Deposition Patterns and Trends

3.2.3.1 Annual Depositions

Sulfur Species

Table 3-9 presents annual dry depositions in kilograms per hectacre (kg/ha) of SO_2 and SO_4^{2-}, all expressed as sulfur (S), averaged by subregion for the years 1987 through 1995. The highest depositions were measured in the northeast and midwest subregions; the lowest were measured at the upper northeast sites. The data for the eastern sites combined show a 29-percent reduction in deposition of SO_2 (as S) from 1989 through 1995, and only a 6-percent reduction in deposition of SO_4^{2-}. These percentage reductions in depositions are lower than comparable reductions in concentrations that were discussed in Section 3.2.1.1. The calculated reduction in total sulfur is 27 percent. The eastern data indicate about 85 percent of sulfur deposition is in the form of SO_2. Changes in sulfur depositions are more pronounced in three (northeast , upper northeast, and upper midwest) of the six eastern subregions although still significant in the other three subregions. Despite the low average in 1995, there is no apparent trend in the data from the western sites. Throughout the western network, SO_2 deposition represents about 65 to 70 percent of total sulfur deposition.

To illustrate variability in annual dry depositions, maps of annual fluxes of total sulfur for the years 1989, 1992, and 1994 are presented in Figures 3-56 through 3-58. The distribution of sulfur deposition is similar from year to year with an area above 6.0 kg/ha, extending from southwestern Indiana across central New York. The map of sulfur depositions corresponds well with the maps of SO_4^{2-} and SO_2 concentrations discussed in Section 3.2.1 and reflects the distribution of SO_2 sources shown in Figure 3-2. Peak depositions are estimated for eastern Ohio and western Pennsylvania. Sharp gradients are observed across northern New England and the upper Midwest. Values above 3.0 kg/ha are observed as far south as Georgia Station (Site 159), but decrease to about 1.0 kg/ha on the Florida panhandle.

Average sulfur depositions for the western sites are less than 1.0 kg/ha, except for Chiricahua, located in southeastern Arizona.

Nitrogen Species

Table 3-10 lists annual dry deposition rates of HNO_3 and NO_3^-. The HNO_3 and NO_3^- fluxes are expressed as nitrogen. The highest regional average HNO_3 depositions were measured in the northeast and midwest subregions in 1994. The highest depositions of NO_3^- are consistently measured in the midwest. Total nitrogen deposition, on a regional average basis, is highest in the northeast. The data averaged over all eastern sites show an increase of about 17 percent in HNO_3 and total NO_3^- depositions with no change in deposition of NO_3^-.

Figures 3-59 through 3-61 show maps of annual average dry depositions of total nitrogen for 1989, 1992, and 1994. Most of the sites in the eastern network, except along its periphery, show depositions above 2.0 kg/ha for all 3 years. Depositions for sites along the Appalachian chain are also less than 2.0 kg/ha, showing the influence of complex terrain on atmospheric nitrogen species. In general, patterns are similar from year to year, although in 1994 the areal coverage of depositions in excess of 4.0 kg/ha is considerably greater than in the two previous years. The data for the eastern sites in Table 3-10 show an increase in nitrogen deposition over the period of record.

The maximum value shown throughout the western network over the 3 years is 1.4 kg/ha. About half of the sites showed depositions less than 1.0 kg/ha. The lowest value was observed at Glacier NP.

Ammonium

Annual average dry depositions of NH_4^+ by year and by subregion are shown in Table 3-11. The midwestern subregion shows the highest annual NH_4^+ depositions, followed by the northeast subregion , and then the south-central subregion. The other three subregions in the eastern network show much lower depositions. Averaged data from the western sites show NH_4^+ depositions all less than 0.13 kg/ha.

Figure 3-62 shows annual average NH_4^+ fluxes for 1992 as an example year. Three areas with depositions above 0.5 kg/ha are shown on the map: Indiana and Ohio, eastern Tennessee and North Carolina, and the mid-Atlantic states. The highest depositions are shown for midwestern monitors and one site (Arendtsville) in southeastern Pennsylvania.

3.2.3.2 Weekly Depositions

Sulfur Dioxide

Five sites were selected from five eastern subregions to illustrate weekly distributions of deposition rates: Vicennes, IN (Site 140), Cowetta, NC (Site 137), Arendtsville, PA (Site 128), Perkinstown, WI (Site 134), and Woodstock, NH (Site 109). Figures 3-63 through 3-67 show time series of weekly SO_2 concentrations, deposition velocities, and depositions for 1995 for these five sites. All five figures show the annual cycle of deposition velocities, gradually rising from about 0.2 cm/sec in the winter to between 0.4 and 0.5 cm/sec in the middle of the summer. The curves of SO_2 V_d show little weekly variability superimposed on the annual cycle. Higher SO_2 concentrations are observed in the cold months with significantly higher concentrations at the sites near major sources. For example, the Indiana monitor measured weekly SO_2 levels as high as 40 $\mu g/m^3$; whereas the New Hampshire monitor measured concentrations typically at levels around 1 $\mu g/m^3$ with higher concentrations in the 2 to 4 $\mu g/m^3$ range. The range in SO_2 concentrations is as high as a factor of 6.0 as compared to the roughly factor of 2.0 change in deposition velocities. The distributions of depositions shown in the five figures follow more closely the patterns of concentrations, rather than deposition velocity.

To investigate the relationship between SO_2 concentrations and depositions Figure 3-68 gives a scattergram of weekly concentrations and depositions for 1995 for the five sites combined. The data show a good relationship, with a correlation coefficient of 0.87. Despite the complexity of dry deposition processes, the relationships are fairly consistent from site to site, suggesting that the variability in deposition is largely driven by variability in concentration. The relationship is stronger for lower concentrations, as shown in Figures 3-69 and 3-70. Figure 3-69 shows a scattergram for SO_2 concentrations (as S) less than or equal to 2.0 $\mu g/m^3$. Figure 3-70 provides a scatter diagram for SO_2 levels (as S) greater than 2.0 $\mu g/m^3$. Evidently, the efficiency of the deposition processes decreases somewhat as SO_2 concentrations increase.

Sulfate

Figures 3-71 through 3-75 show time series of weekly average SO_4^{2-} deposition velocities, concentrations and depositions for 1995 for the same five sites. The distributions of deposition velocities do not show a strong annual cycle like SO_2, except perhaps for a general tendency for higher values in spring and early summer. The aerosol deposition velocities are more related to changes in meteorological conditions, rather than changes in vegetation. Because of

enhanced atmospheric photochemistry in the warmer months, SO_4^{2-} concentrations and depositions peak in the summer. SO_4^{2-} concentrations are higher at the Indiana and Pennsylvania monitors and much lower at the Woodstock, NH site.

Figure 3-76 provides a scattergram of weekly SO_4^{2-} concentrations versus depositions for 1995. Again, there is a consistent relationship between concentrations and depositions across all five stations.

Nitric Acid

Time series of HNO_3 deposition velocities, concentrations, and depositions (fluxes) for 1995 for the same five sites are given in Figures 3-77 through 3-81. The curves for deposition are dissimilar among the five sites. Only the Vincennes site shows an annual cycle with maximum velocities in the summer. However, the weekly variability is also considerable. The North Carolina site shows the highest HNO_3 V_d in the spring. No seasonal or annual cycles are apparent in the data from the other three sites. Concentrations are generally higher in the warm months with a few exceptionally high values in the winter. Depositions generally follow concentrations although there seems to be more of an influence of deposition velocity on depositions than for SO_2 and SO_4^{2-}.

Figure 3-82 shows a scattergram of HNO_3 depositions versus concentrations for 1995 data aggregated from the five sites. The data again show a good linear relationship (correlation coefficient) across the five sites and for an order of magnitude range in both concentrations and depositions.

3.2.3.3 Trend Analysis

As an initial test of trends in dry deposition, linear regressions (deposition versus year) were calculated for depositions of SO_2, SO_4^{2-}, total dry sulfur, HNO_3, NO_3^-, and total NO_3^- from 1989 through 1995 for all the eastern sites combined. The results are shown in Figures 3-83 through 3-88, respectively. Downward trends are indicated for the sulfur species although the trend lines are not considered statistically significant. The downward slopes for SO_2 and total sulfur are greater than for SO_4^{2-}, consistent with the results for concentrations. The reductions in depositions of sulfur species are lower than the corresponding reductions in concentrations.

The slopes for the regression lines for HNO_3 and total NO_3^- are slightly positive; the slope for NO_3^- aerosol deposition is 0.0. These results are not considered statistically significant.

Depositions of sulfur and nitrogen species measured throughout the western network exhibit no trends.

3.3 Wet Deposition

The purpose of wet deposition monitoring within CASTNet is to facilitate the comparison of dry deposition rates with wet deposition rates and to calculate total deposition. Therefore, wet deposition monitoring was initiated at those CDN sites that are 50 km or further from the nearest NADP monitoring site. Figure 2-4 shows the location of the CDN wet deposition sites. Except where noted, the following sections discuss results generated by data collected at CDN sites and those NADP sites that correspond to CDN dry deposition only sites. Data from the two networks were combined since, in most cases, the small number of CDN wet deposition sites does not allow for meaningful analysis or conclusions on a regional basis.

3.3.1 Concentrations in Precipitation

3.3.1.1 Annual Average Concentrations

Sulfate

To assess variability in annual averages, maps of annual SO_4^{2-} concentrations for the years 1990, 1992, and 1994 are presented in Figures 3-89 through 3-91. Similar concentration patterns were noted for these 3 years, with highest concentrations (3.0 mg/L or above) appearing in southern Illinois, eastern Michigan, Ohio, south-central Pennsylvania, and central West Virginia. The lowest concentrations were exhibited during 1994.

Nitrate

Figures 3-92 through 3-94 show the annual NO_3^- concentrations for 1990, 1992, and 1994, respectively. These figures show that the highest concentrations (above 2.5 mg/L) were observed at only two sites in 1990 (Sites 124 and 128). A high concentration region was evident in 1992 and included sites in the upper midwest (Site 134), midwest (Sites 114, 115, 123, and 157), and one site in the northeast region (Site 128). This area receded to three sites in the Ohio-Michigan region in 1994. The overall 1994 concentrations were the lowest of the 3 years.

pH

The lowest annual pH values (less than or equal to pH 4.2) occurred at sites in New York, Pennsylvania, West Virginia, and Virginia in 1990 (Figure 3-95). Only two of these sites (Sites 119 and 128) maintained the low pH levels in 1992 with Site 114 mimicking them in 1994 (Figures 3-96 and 3-97). In general, the lowest pH values in the network were detected in western New York, Ohio, Pennsylvania, and West Virginia. Except for Sites 114 and 119, a steady rise in pH values can be detected from 1990 to 1994. Sites 114 and 119 also did not exhibit lower SO_4^{2-} and NO_3^- concentrations over this period. The pH values of the western sites were approximately 0.5 pH units higher than the eastern sites.

Ammonium

During 1990, 1992, and 1994, concentrations above 0.5 mg/L occurred primarily in agricultural areas (Figures 3-98, 3-99, and 3-100, respectively). NH_4^+ concentrations were less than or equal to 0.5 mg/L for the western sites. There was a decrease in NH_4^+ values for most of the sites in the higher concentration area between 1990 and 1994 with the highest concentrations occurring in 1992.

Chloride

Annual concentrations for 1992 and 1994 only are shown in Figures 3-101 and 3-102. These annual maps show, as would be expected, that sites on or near the coast detected higher Cl^- levels with respect to inland sites. Among inland sites, those sites paralleling the East Coast exhibited generally higher Cl^- levels than sites further inland. Chloride concentrations at the western sites mirrored concentrations at the inland eastern sites. Declines in Cl^- concentrations were exhibited by individual sites but not by an area or a region.

Cations

A higher concentration area of Ca^{2+} was noticeable in the midwest and upper midwest for 1994 (Figure 3-103). This high concentration area was also apparent in other years (not shown) and seems to be correlated with agricultural sites as with NH_4^+. Concentrations from the western sites were similar to concentrations at the midwestern agricultural sites. Of the four cations, Ca^{2+} exhibited the highest concentrations.

Figures 3-104 through 3-106 show annual concentrations for 1994 for Na^+, Mg^{2+}, and K^+, respectively. Sodium concentrations followed the same pattern as for Cl^-; sites with the highest concentrations were detected on the coast and sites paralleling the eastern seaboard exhibited concentrations between the coastal sites and those further inland (Figure 3-104).

There were no noticeable areas of high concentration for Mg^{2+} and K^+. With the exception of the coastal and Atlantic seaboard sites for Na^+, concentrations for all three cations were measured on the same order of magnitude. Concentrations at the western sites were similar to those for the eastern sites.

3.3.1.2 Quarterly Average Concentrations

Time series of quarterly average concentrations of SO_4^{2-} are presented in Figures 3-107 through 3-109 for Sites 114 (Deer Creek State Park, OH), 126 (Cranberry, NC), and 128 (Arendtsville, PA), respectively. A very pronounced seasonal pattern was evident for all three sites with SO_4^{2-} concentrations peaking during second and third quarters and dropping off during the fourth and first quarters. This seasonal fluctuation was either non-existent or not as strong for sites in the periphery of the network. The western sites showed seasonal fluctuation with same pattern as the eastern sites. Figures 3-110 and 3-111 show quarterly SO_4^{2-} concentrations at Sites 161 (Gothic, CO) and 167 (Chiricahua, AZ), respectively.

Nitrate values at the three eastern sites (114, 126, and 128) also peaked primarily during second and third quarters. However, the pattern was not as pronounced as that for SO_4^{2-}, especially for Site 114. This site had some peaks occurring during the fourth and first quarters. The two western sites showed strong NO_3^- peaks during the same quarters as the eastern sites. Figures 3-112 and 3-113 illustrate the NO_3^- seasonality for Sites 126 and 167, respectively.

Sites 126 and 128 displayed strong seasonality for NH_4^+ with peaks occurring during the warm quarters, but Site 114 exhibited some peaks during the fourth quarter as well. In the west, NH_4^+ peaked during the second and third quarters at Sites 161 and 167.

At the three eastern sites (114, 126, and 128), pH values peaked (lower acidity) during the fourth and first quarters and dipped during second and third quarters (Figures 3-114 through 3-116, respectively). This pattern is consistent with the observation that SO_4^{2-} and NO_3^- values

peaked during the summer months, resulting in precipitation with lower pHs with respect to the winter months. The western sites did not exhibit seasonality for pH, perhaps due to lower concentrations of SO_4^{2-} and NO_3^- with respect to eastern sites.

There were no noticeable patterns for the rest of the analytes, except for Cl^- for the western sites. Site 161 exhibited Cl^- peaks mostly during the third quarter (Figure 3-117), and Site 167 exhibited peaks during the second quarter (Figure 3-118).

3.3.1.3 Summer and Winter Averages

Seasonal behavior is also demonstrated by time series of summer (June through August) and winter (December through February) averages of analytes. Figures 3-119 and 3-120 illustrate the summer and winter averages of SO_4^{2-} for seven eastern sites. Both figures show that the summer averages were generally more variable from year to year than the winter averages. Sites 126 and 180 clearly had higher summer concentrations of SO_4^{2-}. Site 114 average values also illustrated the same difference, except for 1991 when winter SO_4^{2-} values approximated typical summer values. The peripheral sites, 134 and 156, showed more variability in SO_4^{2-} concentrations during the summer, but demonstrated only a relatively small difference in summer versus winter concentrations with respect to Sites 114, 126, and 180. Site 125 summer averages showed great variability from year to year but an inconsistent pattern with respect to winter averages.

Figure 3-121 (summer and winter average concentrations for Sites 161 and 167) shows greater year-to-year variability among summer concentrations and lower concentrations during the winter with one exception (the winter 1990 value for Site 167).

The difference between summer versus winter NO_3^- concentrations is illustrated in Figures 3-122 and 3-123. Both figures show that NO_3^- concentrations were higher and more variable from year to year during the summer. Figure 3-124 demonstrates the same correlations for Sites 161 and 167 for summer versus winter NH_4^+ concentrations.

3.3.1.4 pH versus Sulfate and Nitrate

To briefly investigate the association between pH, SO_4^{2-}, and NO_3^-, 1994 concentrations of SO_4^{2-} and NO_3^- from eastern CDN sites only were regressed against hydrogen ion (H^+) concentrations

in Figures 3-125 and 3-126, respectively. An r^2 value of 0.79 for SO_4^{2-} versus H^+ concentrations indicates a relatively strong association between SO_4^{2-} and pH values. Nitrate, however, does not appear to be as strongly correlated with pH and/or H^+ concentrations ($r^2 = 0.48$). These results indicate that SO_4^{2-} concentrations were more critical in affecting the pH of precipitation at the eastern CDN sites.

3.3.1.5 Trends Analysis

Trends in precipitation concentrations were evaluated by performing linear regressions on annual, summer and winter averages on a subregional and regional basis (east and west) for SO_4^{2-} and NO_3^- (Tables 3-12 and 3-13). Reductions in annual SO_4^{2-} concentrations were considered significant only for the upper northeast and southern periphery subregions. Although the eastern region as a whole did not exhibit a significant trend, the p-value of 0.07 was very close to the significance level of 0.05, indicating a downward trend. Two subregions, the upper midwest and south-central, also showed downward correlations with p-values of 0.09 for both. The western region did not show any trends. Annual regression plots of SO_4^{2-} for each subregion and region are presented in Figures 3-127 through 3-134.

The regressions based on the summer average SO_4^{2-} concentrations did not show any significant reductions whereas the winter concentrations showed significant reductions for three subregions and the eastern region as a whole.

There were no significant trends in annual and summer data for NO_3^-. Winter concentrations exhibited significant reductions for three subregions (upper northeast, northeast, and south-central). The eastern region showed a downward trend that is not considered statistically significant with a p-value of 0.07.

Annual average precipitation concentrations by analyte for CDN sites only from 1990 through 1994 are presented for reference purposes in Tables 3-14 through 3-22. The last four columns of these tables also present the 5-year mean, the standard deviation of the mean, the coefficient of variation (CV), and the percent difference (%D).

3.3.2 Wet Deposition Patterns and Trends

Annual average depositions by analyte for 1990 through 1994, 5-year mean averages, standard deviations of the 5-year mean averages, CVs, and %Ds for the CDN wet deposition sites are presented for reference purposes in Tables 3-23 through 3-31. Tables 3-32 and 3-33 present the same information for SO_4^{2-} as sulfur (S) and for NO_3^- as nitrogen (N), respectively.

3.3.2.1 Annual and Period Average Depositions

Deposition values for the more significant analytes such as SO_4^{2-}, NO_3^-, and pH as hydrogen ion are presented as annual averages for the years 1990, 1992, and 1994. Depositions of NH_4^+ and Cl^- are presented as period averages (i.e., 1990 to 1994) and depositions of Ca^{2+}, K^+, Na^+, and Mg^{2+} are presented in the table formats described above (Tables 3-27 through 3-30).

Sulfate

The combined CDN/NADP annual average deposition rates for SO_4^{2-} are presented in Figures 3-135, 3-136, and 3-137 for 1990, 1992, and 1994, respectively. Figure 3-135 shows that the high SO_4^{2-} deposition area (25 kg/ha or above) through Ohio, West Virginia, and Pennsylvania continues west into Indiana and central Illinois, south through Kentucky into eastern Tennessee and reaches northward to include Maryland, New Jersey, and southern New York. The highest deposition occurred in northwestern Pennsylvania with a value of 43.4 kg/ha. Figure 3-136 illustrates that this relatively large high SO_4^{2-} deposition area shrunk in 1992 and covered Ohio, Pennsylvania, West Virginia, and southern New York, and included the high elevation site (126) in North Carolina. This same general area, but slightly larger, is depicted in Figure 3-137 for 1994 with high SO_4^{2-} deposition also measured in eastern Tennessee.

Nitrate

The year-to-year variations of NO_3^- values for 1990, 1992, and 1994 are shown in Figures 3-138, 3-139, and 3-140, respectively. The highest NO_3^- depositions occurred in northern Pennsylvania and southern New York for all three years. Sites in New Jersey and West Virginia also exhibited high deposition in 1994. High NO_3^- depositions did not extend as far west or south as did high SO_4^{2-} depositions. This is especially noticeable for 1990.

pH as Hydrogen Ion

Hydrogen ion (H^+) depositions for the CDN/NADP sites for 1990, 1992, and 1994 are presented in Figures 3-141, 3-142, and 3-143, respectively. The highest H^+ depositions in 1990 occurred over Ohio, West Virginia, Pennsylvania, southern New York, and one site in eastern Tennessee. Depositions for H^+ in Ohio and southwestern New York showed a steady decrease from 1990 to 1994, whereas H^+ depositions in West Virginia and Pennsylvania dipped in 1992 but rose slightly in 1994. The highest H^+ depositions for all 3 years were measured in northwestern Pennsylvania. The Catskill-New York site did not exhibit any change in H^+ deposition over the 3 years, and H^+ deposition at the eastern Tennessee site rose back to 1990 levels after a decline in 1992.

Regionally, the midwest experienced the greatest reduction (32.0 percent) in H^+ deposition between 1990 and 1994, and the northeast had the smallest (13.4 percent). The northeast region also had the highest regional average H^+ depositions in 1990 (0.67 kg/ha) and in 1994 (0.58 kg/ha). All regions declined in regional H^+ depositions, except for the southern periphery. The three sites in this group exhibited a 14.8-percent increase in average H^+ deposition.

Ammonium

The highest NH_4^+ depositions were measured over the midwestern region with an extension into Pennsylvania as depicted in Figure 3-144. The relatively high CVs in Table 3-26 are indicative of an up and down pattern over the years in NH_4^+ depositions for many of the CDN sites rather than a steady downward trend.

Chloride

Figure 3-145 shows that Cl^- depositions are greatest at the coastal sites and decline steadily as one moves away from the coasts. The southern periphery sites and those south-central sites paralleling the Gulf Coast as well as sites paralleling the East Coast all exhibited higher Cl^- depositions than sites further inland.

Cations

Tables 3-27 through 3-30 present the yearly deposition averages and accompanying statistics for Ca^{2+}, Na^+, Mg^{2+}, and K^+, respectively for CDN sites only. In general, deposition values

for Ca^{2+}, Na^{+}, and Mg^{2+} declined for most CDN sites from 1990 to 1994. High CV values indicate an up and down pattern at most sites. At all but four sites, K^{+} depositions increased from 1990 to 1994.

3.3.2.2 Summer and Winter Averages

Depositions, like concentrations, also exhibited seasonality. SO_4^{2-}, NO_3^-, and NH_4^+ depositions were higher in the warmer months than in the colder months. Figures 3-146 and 3-147 show this seasonality (summer versus winter) for SO_4^{2-} at eastern Sites 114, 134, 156, and 180, and western Sites 161 and 167, respectively. Deposition values for SO_4^{2-} also showed greater variability from year to year in the summer months than during the winter months.

Figure 3-148 shows the same summer versus winter difference for NO_3^- for the same eastern sites, except for the NO_3^- deposition value in 1991 at Site 114. Summer versus winter values for NH_4^+ are plotted in Figure 3-149 for the same four eastern sites, and in Figure 3-150 for the western sites.

3.3.2.3 Depositions and Concentrations

For the most part, wet depositions and concentrations follow the same pattern. This was illustrated with the summer and winter averages and is further exemplified in Figures 3-151 through 3-155. Figures 3-151 and 3-152 show average quarterly SO_4^{2-} concentrations and depositions plotted together for Sites 126 and 128, respectively. At both sites, SO_4^{2-} concentrations and depositions peaked during second and third quarters. The difference in magnitude between the peaks and valleys in deposition values is much greater than in the concentrations.

The same relationship is seen for NO_3^- in Figures 3-153 and 3-154, and for NH_4^+ at Site 126 only in Figure 3-155.

On occasion (e.g., second quarter 1991 in Figures 3-152 and 3-154), depositions either decreased when concentrations increased, or they did not increase as greatly as concentrations did. Other scenarios include instances of relatively large drops in deposition with respect to rather small decreases in concentration (e.g., fourth quarter 1989 in Figure 3-154). Such cases

provide opportunities for further investigation into the effects of meteorological parameters on deposition rates.

3.3.2.4 Trends Analysis

The trend analyses presented in this section are based on linear regressions of deposition versus year conducted on the combined CDN/NADP database. Regressions were calculated for SO_4^{2-} as S and NO_3^- as N for all eastern sites combined and for each subregion for 1989 through 1995. The results are summarized in Table 3-34.

Significant downward trends were indicated for the sulfur species for the eastern region, and for the upper northeast, northeast, midwest, and south-central subregions. No significant reductions were indicated for nitrogen. However, the eastern and western regions and the upper northeast subregion exhibited downward trends with p-values close to significance (0.07, 0.07, and 0.08, respectively). Figures 3-156, 3-157, and 3-158 illustrate the results of regression analyses for sulfur for the eastern region, and the upper northeast and south-central subregions, respectively. Figures 3-159 and 3-160 show the strong downward trends of nitrogen depositions for the eastern and western regions, respectively, even though the results are not considered statistically significant.

3.4 Total Deposition of Sulfur and Nitrogen Species

Dry and wet depositions of sulfur and nitrogen species are summed, analyzed, and presented in this section. The analyses generally follow those used to present the concentration, dry deposition, and wet deposition measurements discussed in previous sections.

Figure 3-161 shows annual average total sulfur depositions averaged over the 6-year period 1989 to 1994. Six-year average depositions above 10 kg/ha were observed across most of the eastern network. Depositions above 15 kg/ha were observed at sites located in and downwind of the major source region of SO_2 emissions. Depositions drop off significantly along the peripheries of the network.

Depositions at the western sites are at or below 3 kg/ha with the Chiricahua site (167) showing depositions about three times higher than the other western sites.

The variability in annual depositions are illustrated in the maps of annual averages shown in Figures 3-162 through 3-164 for 1989, 1992, and 1994, respectively. Similar patterns of depositions were observed in the 3 years with the highest values occurring in 1989. The geographic coverage of higher (above 15 kg/ha) depositions is smallest in 1992. The area with depositions above 15 kg/ha increased into New Jersey and Maryland in 1994.

The percentages of total deposition that are in the form of dry deposition are given in Figure 3-165 for the 6-year average and in Figure 3-166 for 1994. The patterns are similar in the two figures. The higher percentages of dry deposition occur along the Ohio River into New York State and also in the mid-Atlantic states. An area of relatively lower percentages exists along the Appalachians into central Pennsylvania. This area could reflect the higher precipitation that occurs in the mountains. Other regions with lower percentages occur in regions with low ambient concentrations (e.g., New England and the upper midwest). Lower percentages are also observed in the deep South, a region with high rainfall.

Table 3-35 provides subregional averages of total sulfur deposition by year and also percentages of dry deposition. The calculated total depositions show about a 32-percent reduction in sulfur deposition for all of the eastern sites combined. The downward trend is shown consistently for every subregion. Even the western sites show a downward trend. Figure 3-167 shows a linear regression for the eastern sites combined. The regression plot verifies a statistically significant reduction in total sulfur deposition.

Figure 3-168 shows 6-year average rates of total deposition of nitrogen species. Most of the eastern network has values above 5 kg/ha. Two deposition values above 8 kg/ha were observed. Depositions drop off along the peripheries of the network. Depositions of nitrogen species in the western network are 2.0 kg/ha or less. Again, the Arizona site monitor experienced the highest deposition rate.

Annual average total nitrogen depositions are shown in Figures 3-169 through 3-171 for 1989, 1992, and 1994. The patterns of depositions are similar from year to year, with most of the eastern sites observing values above 5 kg/ha. In 1989, the highest levels occurred in Ohio, West Virginia, and Pennsylvania. In 1992, one value above 8.0 kg/ha was observed in

New York. In 1994, the area of peaks shifted to northern Virginia, eastern Pennsylvania, and New Jersey.

Percentages of dry deposition are given in Figure 3-172 for the 6-year averages and in Figure 3-173 for the year 1994. The percentages calculated for most of the eastern sites are above 40 percent. Again, an area of lower values exists along the Appalachian chain. A sharp gradient is observed over New England. The percentages for dry nitrogen deposition are higher in the South than for the corresponding percentage for dry SO_4^{2-} deposition. The percentages for the western sites are at or above 40 percent.

Table 3-36 lists total nitrogen deposition by subregion and by year and also shows the percentages of dry deposition. The calculated total depositions rates of nitrogen species exhibit no trend for eastern sites combined. The table shows a small reduction of the northeast and upper northeast subregions. However, the linear regression analysis of total nitrogen deposition versus year, shown in Figure 3-174, shows no significant trend.

3.5 Ozone Concentrations

The CASTNet O_3 network was designed, in part, to provide information on the distribution of O_3 across rural areas of the United States. As discussed in Chapter 2.0, the siting criteria used to locate sites in the network and the attention given to physically locating sites to provide the greatest regional representativeness possible allow the O_3 measurements to give at least a qualitative analysis of geographic patterns throughout the eastern United States. The data provide estimates of exposure statistics and allow gauging compliance with national air quality standards. The data also allow the analysis of the effects of terrain and other site characteristics on O_3 concentrations.

O_3 concentrations are regulated by the National Ambient Air Quality Standard (NAAQS) of 0.12 part per million (ppm) hourly average. In practice, O_3 levels of 125 ppb or greater are counted as exceedances of the current NAAQS. A violation of the NAAQS occurs when the fourth highest hourly concentration measured in any 3-year period equals or exceeds 125 ppb.

In November 1996, EPA proposed eliminating the one-hour primary standard and replacing it with an 8-hour standard. The proposed eight-hour standard was set at 0.08 ppm. The 0.08-ppm

level was proposed in November 1996 in terms of the third highest daily maximum 8-hour concentration, averaged over 3 years. In July 1997, EPA promulgated a new standard in terms of the fourth highest daily 8-hour concentration. A violation of the new NAAQS would occur when the 3-year average of the fourth highest, daily, running 8-hour averages exceeds 84 ppb.

EPA had also proposed a revised secondary standard -- either identical to the proposed primary standard or establishing a "seasonal SUM06" secondary standard. The SUM06 standard is expressed as the sum of hourly O_3 concentrations summed over 12 hours per day (8:00 a.m. to 8:00 p.m.) during the 3-month period when O_3 concentrations are at their highest. The numerical value of the standard is 25 parts per million hours (ppm-hr). Although EPA did not promulgate the SUM06 standard, SUM06 provides a measure of the exposure of vegetation and crops to O_3 during the growing season.

W126 is another measure proposed by Lefohn and Runeckles (1987) for examining O_3 damage to forests and crops. W126 is an S-shaped function that weights O_3 concentrations in a manner that emphasizes high values (i.e., >80 ppb) and de-emphasizes low values (i.e., <30 ppb), based on the expectation that the higher concentrations are more harmful to crops. Another measure of overall exposure is simply the annual average concentration.

The CASTNet O_3 database was used to calculate the measures discussed above for each monitoring site and each year since 1987. Running eight-hour concentrations were calculated for each hour of the day. SUM06 and W126 statistics were based on rolling 3-month averages.

3.5.1 Annual Averages

Annual averages by site and arranged by subregion are listed in Table 3-37. Annual concentrations measured throughout the eastern network ranged from around 20 ppb to about 50 ppb. The highest annual averages occur at mountaintop sites (e.g., 118, 120, and 126) along the Blue Ridge and Appalachian Mountains, while the lowest annual averages were recorded at sites in steep valleys (e.g., Sites 119 and 121) and in suburban areas (e.g., Sites 116 and 146). Although there is considerable geographic variability in annual averages, there is little year-to-year variability at individual stations. Unlike SO_2 and SO_4^{2-}, there is no discernible trend in annual averages. The lower annual averages were recorded at monitors situated far away from major source regions and at stations significantly influenced by local nighttime sinks (discussed

later). The higher annual averages were observed in 1995 and 1988, while lower averages were recorded in 1992.

Data for the western sites show annual averages ranging from 21 ppb in Montana to 52 ppb in southeastern Wyoming. The annual averages typically exceed 40 ppb, except for Glacier NP, MT (Site 168) and Reynolds Creek, ID (Site 163). These two sites are situated at the two lowest elevations in the western network. In general, the annual averages measured at the western sites are higher than those recorded in the east. The relatively high annual concentrations at the western sites are consistent with the high annual levels at the mountaintop eastern sites.

3.5.2 Hourly Concentrations

Table 3-38 shows the peak hourly O_3 concentrations by site and subregion for each year the site was operational. Table 3-39 shows the frequency of hourly concentrations above 125 ppb by site, subregion, and year. The data in these two tables allow a compliance analysis with respect to the current 1-hour NAAQS. During the summer of 1988, several sites measured concentrations above 125 ppb, and several sites showed violations of the NAAQS. The summer of 1988 was unusually hot and dry in most of the eastern United States and resulted in a season of very high O_3 levels. Figure 3-175 shows the number of values greater than 124 ppb at each site for 1988 and for all other years combined, separated by a diagonal.

After 1988, the monitors with three or more exceedances and with violations of the NAAQS were limited to locations in the Washington - New York corridor (i.e., the Maryland, New Jersey, and West Point, New York sites). Other sites recorded between one and three exceedances of the 1-hour standard, but no violations, from 1989 through 1995. In general, these were rural-agricultural sites located approximately 50 to 75 km from a major urban center.

Peak hourly concentrations measured throughout the western network were generally much lower that the eastern measurements, although one hourly measurement in southern Arizona exceeded 125 ppb. No violations of the current NAAQS were recorded at the western sites.

3.5.3 Eight-Hour Concentrations

Running 8-hour O_3 concentrations were calculated for every day throughout the sampling record. Daily peaks were selected from the running 8-hour values. Figures 3-176 through 3-178 show the fourth highest, daily 8-hour concentration for each site for the years 1993 through 1995. Figure 3-179 provides averages of the fourth highest values for each site. A violation of the proposed NAAQS would occur if a value in Figure 3-179 equals or exceeds 85 ppb. The 3-year averages show that 15 eastern sites would have recorded a violation of the proposed primary standard for the 1993 to 1995 period. Figure 3-180 shows the maximum and minimum number of days in any year from the monitoring record with levels above 80 ppb. A site with a minimum of 4 days or more would have experienced a violation for every 3-year period in the data record. The fourth highest 8-hour concentration for each site by subregion are shown for 1988 to 1991 in Figure 3-181 and for 1992 to 1995 in Figure 3-182. Sites with 3-year averages above 85 ppb would have experienced a violation of the proposed NAAQS.

Concentrations above the proposed primary standard were measured in the midwest and northeast subregions with a few high values in the south-central subregion. None of the western sites recorded annual maximum running 8-hour O_3 concentrations above 85 ppb. Values ranged from 43 to 72 ppb.

3.5.4 SUM06

The measure SUM06 has been proposed as a secondary standard to protect human welfare and the environment. Table 3-40 lists maximum SUM06 by site, subregion, and year. The table also shows the 3-month period in which the maximum SUM06 was recorded for each year. A majority of sites show SUM06 values consistently above 25 ppm-hr, the proposed numerical limit. The peak SUM06 values were most often recorded in June through August, although occasionally high SUM06 levels were earlier in the year, March through May.

Figure 3-183 illustrates peak SUM06 levels for 1995. Values above 25 ppm-hr were observed across most of the Midwest and Mid-Atlantic states, from Illinois to New Jersey. Most of the southeastern sites recorded values above 25. No values above 25 ppm-hr were measured in Wisconsin, Michigan, New England, and along the southern edge of the network on the Florida

panhandle and in Arkansas. Three sites in the core of the network (i.e., Cedar Creek, WV; Prince Edward, VA; and Beaufort, NC) recorded values less than 25 ppm-hr in 1995.

Four SUM06 values above 25 ppm-hr were recorded in the western network since 1991.

3.5.5 W126

Table 3-41 lists maximum W126 by site, subregion, and year. Twenty-five ppm-hr was chosen as a numerical measure for W126 for the purpose of comparison to SUM06 levels. The highest W126 values were recorded in 1988. The highest level (51.8 ppm-hr) recorded throughout CASTNet was in June through August 1988 at Site 122 (Oxford, OH). Many high values were also recorded in 1991.

Figure 3-184 shows the geographic distribution of W126 values measured in 1995. As compared to SUM06, the geographic extent of elevated W126 values is considerably smaller. Values above 25 ppm-hr were restricted to most of the Midwest, the Mid-Atlantic stations, and the two sites in Georgia and Alabama. Measurements throughout the western network were all below 20 ppm-hr.

3.5.6 Geographic Variability

Tables 3-42 and 3-43 summarize O_3 concentrations and the SUM06 and W126 measures for 1995 and 1992 for 12 sites that cover a variety of terrain settings and locations. The year 1995 was selected because it is the most recent year available from the CASTNet database and because it was a relatively high O_3 year. The year 1992 was selected because it was a low O_3 year. During 1995, the fourth highest, daily 8-hour concentration exceeded 85 ppb at half the sites. The 1993 to 1995 averages (Figure 3-179) of the fourth highest, daily 8-hour levels exceeded 85 ppb at the same six sites. The SUM06 levels exceeded 25 ppm-hr at all, but the two remote sites in Maine and Wisconsin and also the Prince Edward, VA site. Peak 1-hour levels exceeded 125 ppb at the two suburban sites in Maryland and New Jersey. In 1992, the fourth highest, daily 8-hour concentrations exceeded 85 ppb at only three sites. SUM06 was

at all the sites, except for the two suburban sites on the east coast and the Cranberry, NC site. Only one peak hourly concentration was above 125 ppb.

The highest annual concentrations were observed at the three mountaintop sites (118, 120, and 126) along the Appalachian chain. The highest hourly and 8-hour levels were measured at the two suburban sites. These two sites had the two lowest annual averages. Eight-hour concentrations are high (above 85 ppb) throughout the midwest and northeast. High SUM06 values are extensive, although there is significant yearly variability.

The geographic differences can be explained by several factors: the proximity of monitors to source regions; terrain and atmospheric boundary layer effects; and day-night differences in photochemistry, scavenging and dry deposition. Differences in diurnal cycles illustrate the influence of some of these factors. Hourly average O_3 concentrations for a site in rolling terrain (Prince Edward, VA), a site in complex terrain (Parsons, WV), a mountaintop site (Big Meadows, VA), and a suburban site (Beltsville, MD) are shown for several annual averaging periods in Figure 3-185. The rolling terrain site exhibits moderate day/night variability, with nighttime values about 50 to 60 percent of daytime peaks. The daytime levels reach a broad peak between the hours of 1200 through 1700. Hourly values for the complex terrain site indicate more day/night variability. Daytime values are about twice nighttime values. The duration of the daytime peak is shorter. The mountaintop site shows a flat diurnal pattern. There is little variability from hour to hour. The suburban site shows the lowest values in the morning near sunrise with daily peaks three to four times early morning levels.

Mountaintop sites are situated typically at elevations above the tops of nocturnal boundary layers that affect valley sites or sites located in rolling or flat terrain. Mountaintop sites are generally in contact with reservoirs of O_3 that have been observed to exist in the planetary boundary layer at night above ground-based inversions. Because mountaintop sites are typically above ground-based inversions, O_3 is not depleted by deposition processes or by scavenging by low-level emissions. Consequently, concentrations are relatively constant throughout the day and are high on an annual basis. Suburban sites are influenced by nearby sources and nighttime sinks. Therefore, suburban sites show more day/night change, have low

values in early morning, and are relatively lower on an annual basis because of low nighttime levels. Nighttime O_3 is depleted by fresh nitric oxide (NO) emissions which are trapped under a ground-based inversion and by dry deposition. Rural rolling terrain and complex terrain sites are subject to the effects of nighttime inversions and deposition losses but most likely not by locally-produced, fresh NO emissions. Hence, nighttime and early morning O_3 levels are low, but there is less day/night change than at the suburban sites. Annual concentrations generally fall between those measured at mountaintop and suburban sites.

3.6 Mountain Cloud Deposition Program

The MADPro is a multi-year study of the deposition of air pollution to high-elevation forests (i.e., above cloud base) in the eastern United States. Clouds can be the primary pathway (approximately 60 percent) for deposition of pollutants to high elevation ecosystems compared with rainfall and dry deposition (approximately 20 percent each) (Murthy and Aneja, 1990; Li and Aneja, 1992). Not only are substantial volumes of cloudwater deposited on surfaces, but higher concentrations of pollutants are found in cloudwater than in precipitation (Mohnen, 1990). This can lead to high fluxes of acidity, sulfur, and nitrogen from cloud droplet interception by forest canopies (Lovett *et al.*,1982; Waldman *et al.*, 1982). High elevation fir and red spruce forests from Maine to North Carolina have shown progressive decline over the past years (Mohnen, 1990; Vong, 1989), evidenced as visible injury, increased mortality, and decreased radial growth (McLaughlin, 1985; Hornbeck and Smith, 1985; Johnson and Siccama, 1983). A consistent body of evidence supports the conclusion that acidic cloudwater is one of the causal factors leading to this recent decline in mountain forests in the United States (Falconer and Falconer, 1980; Mclaughlin *et al.*, 1990, 1991; Eagar and Adams, 1992).

MADPro exists to update and extend the largest previous work on cloud chemistry in the eastern United States -- the Mountain Cloud Chemistry Project (MCCP), also sponsored by the EPA. MCCP was in operation from 1986 to 1989 and was implemented by the Forest Response Program of the National Acid Precipitation Assessment Program (NAPAP). The data collected by the MCCP have been used in the NAPAP Integrated Assessment to evaluate the role of airborne chemicals in the changing condition of forests. Other notable mountain cloud research has been performed in Canada and Europe (see Vong, 1991; Schemenauer, 1988).

The objectives of the MADPro are to measure cloud chemistry, estimate cloud and total deposition, and define source regions which impact high elevation ecosystems in the eastern United States. Further objectives are to relate atmospheric deposition to effects on high elevation forests and to effects on surface water, as well as soil effects such as nitrogen saturation. Since 1994, MADPro has been in operation, using a few high elevation monitoring sites (see Figure 3-186) to gather the requisite data to meet these objectives. Annual reports that include technical details and data analyses of the MADPro results have been prepared for EPA.

3.6.1 MADPro Sites and Automated Cloudwater Collection System

Three automated cloudwater collection sites have been in operation through the warm seasons of 1994, 1995, and 1996 (see Table 3-44): Whitetop Mountain, Mt. Rogers National Recreational Area, VA; Whiteface Mountain, Adirondack State Park, NY; and Clingman's Dome, Great Smoky Mountain National Park, TN. A fourth site in the Catskill Mountains of New York was added in 1995 for a manual sampling program. The automated systems were functionally similar, but some components were variable due to logistics and contingencies. For a detailed description of the cloudwater collection system, see Baumgardner *et al.*, 1997. A generalized system, depicted in Figure 3-187, includes an automated cloud collector for collection and storage of hourly cloudwater samples, a particle volume monitor (PVM) for determination of continuous liquid water content of clouds (Gerber, 1984), a meteorological station for measurement of a suite of parameters necessary for estimating deposition fluxes onto vegetation, a filter pack system to collect weekly measurements of airborne gases and particles and a wet deposition system consisting of a wet/dry collector and rain gauge. Continuous gas monitors were operated at some sites for determination of other atmospheric pollutants of interest (e.g., O_3, SO_2). Also, a DAS collects and stores the electronic information from the various monitors and sensors.

The cloud collector and PVM are interfaced with the DAS, windspeed, rainfall and temperature sensors so that when the liquid water content of a cloud exceeds 0.05 g/m^3, windspeed is higher than 2.5 meters per second (m/sec), ambient air temperature is above freezing [practically, >2 degrees Fahrenheit (°F)], and there is no rainfall, then the cloud collector is activated and projected out of its protective housing.

3.6.2 Total Deposition at Whitetop Mountain, VA

One of the objectives of the MADPro is to obtain measurements of cloud chemistry, precipitation chemistry, and filter pack (dry deposition) chemistry which can be used to model acidic deposition for these three pathways. The methodology for modeling these high elevation deposition fluxes is under development. Average monthly concentrations of SO_4^{2-} and NO_3^- found in dry air (filter pack analyses; expressed in $\mu g/m^3$ dry air) and in samples of rainwater and cloudwater (laboratory analyses of samples; expressed as mg/L water) are shown in Figures 3-188 and 3-189, respectively, for the 3 years of this study (1994 to 1996). Average monthly concentrations of H^+ found in cloudwater and rainwater samples for the same period are shown in Figure 3-190. While a direct comparison will await calculation of deposition values, these figures uphold the previous statement that cloudwater can be the primary pathway for deposition of pollution to high elevation ecosystems. In all three cases over 3 years, the mean concentrations of cloudwater samples are higher (sometimes much higher) than those of the rainwater samples.

3.7 Visibility Network

The purpose of the CASTNet Visibility Network is to measure visibility and related parameters for the purpose of defining status and trends. The measurements are expected to undergo appropriate levels of QA and QC. The data are to be delivered in computerized formats and through various technical reports.

Visibility monitoring includes three measurement types as defined by the Interagency Monitoring of Protected Visual Environments (IMPROVE) program:

1. Scene: Visual characteristics of a scene are monitored to document scene-specific visibility.
2. Optical: Optical properties of the atmosphere are monitored for a scene-independent measure of air quality.
3. Aerosol: Aerosol characteristics (concentration, composition, and size) are determined to relate atmospheric optical properties with various species.

IMPROVE protocols are the basis for optical and scene monitoring and for instrument specifications, siting criteria, sample frequency, QA, and analytical techniques. Primary scene and optical monitoring techniques include automated cameras and nephelometers, respectively.

Aerosols are measured using an annular denuder system (ADS) and three single-stage filter packs. The locations of visibility sites are shown in Figure 3-191.

Each of the ten sites is equipped with an aerosol sampling system. Through November 1995, three sites were equipped with scene monitoring equipment (i.e., cameras), and four sites were equipped with optical monitoring equipment (i.e., nephelometers).

3.7.1 Site-Selection Process

Site survey reports were prepared to present suitability and representativeness information for four new CASTNet visibility monitoring sites in north-central Louisiana, southwestern Kentucky, southern Indiana, and eastern Ohio. Six existing dry deposition sites were upgraded to complete the ten station visibility network. The surveys addressed the siting of: (1) a particle sampler for quantification of SO_4^{2-}, NO_3^-, organic carbon, and trace and crustal elements; (2) a slide camera for documentation of vista conditions; and (3) an ambient temperature nephelometer for quantification of particle scattering. CDN siting criteria were used to evaluate site suitability for particulate and nephelometer measurements. Eastern Fine Particle and Visibility Network (EFPVN) siting criteria (Air Resource Specialists, Inc., 1994) were used to evaluate site suitability for camera operation. The information necessary for site evaluation was divided into five categories: representativeness, suitability, logistics, administration, and identification.

Survey reports were prepared for each candidate area surveyed and delivered to EPA for review. The reports were intended to be used by EPA as the basis for approval or disapproval of a site or recommendations for further study. These reports provided a descriptive summary of the results of the presurvey evaluations and field surveys.

Once a site was selected for inclusion in the network, a complete documentation package was prepared that clearly and fully presents the survey findings. This package includes the site summary, color photographs, maps, and graphics.

3.7.2 Instrumentation

3.7.2.1 Optical

Optec NGN-2 nephelometers are operated according to the following protocol:

- 2-minute integrated average of the ambient scattering coefficient and associated status code are collected at 5-minute intervals.
- Particle free zero air scattering measurements and associated status codes are collected at 30-hour intervals.
- Manual zero air and span (using SUVA 134a refrigerant gas) scattering measurements and associated status codes are performed at operator-initiated intervals (every 2 weeks).

3.7.2.2 Scene

Scene monitoring was performed by 35mm automatic camera systems taking three photographs a day at 0900, 1200, and 1500 hours local standard time. Kodachrome ASA 64 color slide film was used for its fine grain and excellent color reproduction qualities.

Site operators visited each site a minimum of once every 10 days to change film and service the camera system. Operators then sent the exposed film and completed log sheets to Air Resource Specialists, Inc. for processing.

3.7.2.3 Aerosol

The aerosol sampling system includes three independent flow channels, which are operated at 10, 16.7, and 10 Lpm, equipped with mass flow controllers and located in a weather-proof enclosure at 10 meters (m) above ground level. The channel for aerosol SO_4^{2-} and NO_3^- includes a 2.5-micrometer (μm) cyclone followed by a single base impregnated annular denuder tube, followed by a single-stage (Teflon®, nylon) filter pack. The trace/crustal elements and carbon channels include a 2.5-μm cyclone followed by a single-stage filter pack. Trace/crustal element samples are collected on Teflon® filters, while carbon samples are collected on precombusted quartz fiber filters. Figures 3-192 and 3-193 depict the annular denuder and Teflo® and quartz assemblies, respectively. Figure 3-194 shows the combined aerosol sampling system.

Advantages of this aerosol system include the following:

- The 10-m sampling height provides some protection from surface activity and near-surface concentration gradients.
- Mass flow controllers and logging of flows (as hourly averages) permit accurate determination of sample volumes.
- Independent flow systems protect each channel from problems associated with other channels.
- The overall system has the flexibility to meet a variety of monitoring requirements.

3.7.3 Operations

The visibility monitoring network ranged from ten sites in 1993 to nine in 1995 (see Table 3-45). Aerosol samples (24-hour integrated) were collected at all sites, and Optec NGN-2 open-air integrating nephelometers were operated at four sites: Site 510 (Connecticut Hill, NY), Site 528 (Arendtsville, PA), Site 572 (Quaker City, OH), and Site 570 (Sikes, LA). Visual scene photographs were taken three times daily at three sites: Site 510 (Connecticut Hill, NY), Site 528 (Arendtsville, PA), and Site 572 (Quaker City, OH). Aerosol samples are also collected at Site 518 (Shenandoah National Park, VA) on a 14-day schedule to develop comparability data (inter-network precision) with the IMPROVE network. Duplicate aerosol samples are collected at Site 572 (Quaker City, OH) on a 12-day schedule to document intra-network sampling precision.

After each sampling event, filters are shipped to the QST Laboratory, where they are logged in and distributed to analytical laboratories. Through 1995, QST analyzed SO_4^{2-} and NO_3^- on nylon filters; Desert Research Institute (DRI) analyzed organic and elemental carbon on quartz filters; and the University of California at Davis (UCD) analyzed mass, absorbance, and trace/crustal elements on Teflo® filters.

3.7.4 Measurement Period/History

The Work Plan for visibility monitoring was completed in October 1992. Site surveys and report submittals for the four new installations were completed between February 1993 and June 1993. Optec NGN-2 open-air integrating nephelometers were operational at Site 510 (Connecticut Hill, NY, on June 28, 1993), Site 528 (Arendtsville, PA, on June 26, 1993), Site 570 (Sikes, LA, on June 10, 1993) and Site 572 (Quaker City, OH, on July 23, 1993).

Through 1995, automated camera systems were operational at Sites 510, 528, and 572 at the same time as the nephelometers. The collection of aerosol samples began in October 1993 at all 10 sites on a 3-day schedule through July 1994. The schedule changed to a 6-day collection period in August 1994 and continued through November 1995. Site 557 (Alhambra, IL) collected aerosol samples from October 1993 through March 1994. Site 557 was discontinued on March 30, 1994.

Site 518 (Shenandoah National Park, VA) was installed to develop comparability data (inter-network precision) with the IMPROVE network. Site 518 collected aerosol samples on a 3-day schedule from October 1993 through July 1994. The schedule changed to once every 12 days in August 1994 and continued through December 1994. From January through November 1995, Site 518 collected aerosol samples every other Saturday only.

Duplicate aerosol samples were collected at Site 572 (Quaker City, OH) on a 3-day schedule from February through July 1994 to document intra-network sampling precision. Duplicate samples were collected on a 6-day schedule from August 1994 through January 1995. From February through November 1995, duplicate samples were collected on a 12-day schedule.

All visibility network operations stopped on November 14, 1995, at the request of EPA. The network was then reactivated in July 1996.

3.7.5 Quality Assurance

The QA program for the visibility monitoring network is very similar to the CDN QA program described in Sections 2.2.4.1 and 2.2.4.2. The main difference between the two programs is that the laboratory operations and data audits for the visibility QA program also address the activities of the two subcontractor laboratories. The subcontractor laboratories respectively perform carbon analyses via Thermal Optical Reflectance (TOR) on the quartz filters, and mass, trace element, and absorbance analyses via gravimetry, proton induced X-ray emission (PIXE), and light induced proton microscopy (LIPM) methods on the Teflo® filters. Analysis of the nylon filters via IC is performed at QST. Table 3-46 summarizes the results of collocated samples from 1994 for all three filters. Figures 3-195 through 3-198 show the collocated results for some of the analytes as regression plots.

As evident from the results presented in Table 3-46, the trace elements analyzed via PIXE do not exhibit the same levels of precision. In some cases, such as magnesium and zirconium, the high median absolute percent differences (APDs) were most likely due to the small number of collocated samples (1 and 2, respectively). Other cases of high median APDs were probably due to differences in very low concentrations (arsenic, rubidium, strontium, and zirconium). A closer inspection of field and laboratory methods is needed to provide explanations for the rest of the elements exhibiting higher median APDs.

The median APDs for elemental and organic carbon are relatively high as well with values of 24.0 and 19.35, respectively. In the case of elemental carbon the high APDs are, again, most likely due to differences in low concentrations. The value for organic carbon, albeit on the high end, was within project criteria of ± 20 percent for carbon analysis.

One possibility for all the analytes that exhibited higher median APDs may be that some elements, for whatever reasons, may not have deposited evenly on the filters of the collocated filter packs. This is a situation, as mentioned above, that requires further research.

3.7.6 Data Analysis

This section presents an initial analysis of the visibility-related air quality measurements. The year 1994 was selected for the analyses and presentations. More extensive analyses are beyond the scope of this report. Emphasis is given to aerosols that affect atmospheric visual quality. Aerosols are composed of fine and coarse liquid and solid particles in the atmosphere. Fine particles (i.e., less than 2.5 μm in diameter) scatter light and degrade the visual quality of a vista. Fine particles consist of different chemical species like sulfates, nitrates, organic and elemental carbon and soil dust. Annual concentrations of fine particles and their chemical constituents are presented. Seasonal variability is also discussed. Time series of 24-hour average fine particle concentrations and the chemical constituents are presented. Relationships between fine particle concentrations and SO_4^{2-} concentrations and between B_{scat} and fine particles and SO_4^{2-} are also discussed. Finally, photographs of scenic vistas at the Arendtsville site are contrasted for high and low SO_4^{2-} days.

3.7.6.1 Annual Averages

Figures 3-199 through 3-203 show 1994 annual average concentrations (<2.5 μm) of fine particles, SO_4^{2-}, NO_3^-, organic carbon, and elemental carbon, respectively, measured throughout the CASTNet visibility network. Fine particle concentrations range from 8.4 $\mu g/m^3$ in New York to 13.6 $\mu g/m^3$ in eastern Ohio. The NAAQS for $PM_{2.5}$ recently proposed by EPA (62 Federal Register 38421) has a numerical limit of 15.0 $\mu g/m^3$ for annual averages. Sulfate contributes about half the mass of the fine particle concentrations. Annual (fine) SO_4^{2-} concentrations range from 3.5 $\mu g/m^3$ in southern Illinois to about 7.0 $\mu g/m^3$ in Ohio. Total SO_4^{2-} measured at the same Ohio monitor was 7.2 $\mu g/m^3$ in 1994 (see Figure 3-5). Comparing Figures 3-200 and 3-5 demonstrates that smaller SO_4^{2-} aerosols contribute more than 85 percent of the mass of total SO_4^{2-}. On a percentage basis, organic carbon is the second most dominant contributor to fine particle mass. Organic carbon is second to SO_4^{2-} at eight of the nine sites with complete annual data. Nitrate aerosol is second to SO_4^{2-} only at the Bondville site in Illinois. Elemental carbon is consistently fourth on a mass basis. Other trace concentrations (from the Teflo® filters) contribute minute amounts to mass loadings.

3.7.6.2 Summer and Winter Averages

Summer average concentrations of the same five air quality parameters are shown in Figures 3-204 through 3-208. Winter averages are shown in Figures 3-209 through 3-213. Fine particle and SO_4^{2-} concentrations are highest in summer. In fact, summer SO_4^{2-} concentrations are typically three times higher than winter levels. In summer, SO_4^{2-} contributes an even higher fraction of fine particle mass. Fine NO_3^- aerosol levels are higher in winter than in summer. Organic carbon values are somewhat higher in summer with more interstation variability and less seasonal variability. Results for elemental carbon measurements are the opposite of organics with some sites showing higher concentrations in the winter.

3.7.6.3 Monthly and 24-Hour Concentrations

Time series of monthly average SO_4^{2-} and NO_3^- concentrations for all sites are shown in Figures 3-214 and 3-215. These data show the highest SO_4^{2-} concentrations occur in June through July, probably contributing significantly to visibility degradation (discussed later). NO_3^- concentrations peak in the four cold months of December through March. Bar charts that illustrate time series of 24-hour concentrations of fine mass, SO_4^{2-}, NO_3^-, organics, and elemental carbon measured in the summer are given in Figures 3-216 through 3-218 for three sites

(Arendtsville, PA - Site 528; Livonia, IN - Site 573; and Sikes, LA - Site 570). The method for illustrating concentrations of the five chemical species is shown in the legend. For example, concentrations of fine mass are shown by a "star" (*). The bar charts show the magnitude of the concentrations and the percentage contribution to fine mass loadings. For example, the peak 24-hour fine mass value observed at Arendtsville during the summer of 1994 was 38.6 $\mu g/m^3$ on July 31, 1994. On that day, SO_4^{2-} contributed 24.1 $\mu g/m^3$, about 62 percent of the particle mass. Concentrations of other species were all less than 2.4 $\mu g/m^3$. During the summer, 24-hour concentrations varied by more than an order of magnitude with a majority of values above 20.0 $\mu g/m^3$ at the Arendtsville site. Fine particle concentrations were lower at the Livonia monitor. However, several values above 20 $\mu g/m^3$ were observed. Again, SO_4^{2-} was the major contributor to fine mass loading. Fine particle concentrations were even lower at the Sikes, LA site with most observed concentrations below 10 $\mu g/m^3$. Both SO_4^{2-} and organic carbon contributed significantly to fine mass loadings; although for the very highest fine particle concentrations, SO_4^{2-} was the major contributor.

Bar charts for winter measurements are shown in Figures 3-219 through 3-221. Measurements at Arendtsville show much lower fine particle concentrations, with most values less than 10 $\mu g/m^3$. The contribution of SO_4^{2-} has decreased, and the percentage contributions of organic carbon and NO_3^- aerosol are significant and exceed SO_4^{2-} on several days. The Indiana data show fine particle concentrations are lower in winter. Twenty-four average values are typically below 15 $\mu g/m^3$ with three concentrations above 20 $\mu g/m^3$. NO_3^- aerosols and organic carbon are significant contributors to wintertime fine mass. The Sikes, LA fine mass concentrations in winter are typically less than 10 $\mu g/m^3$. SO_4^{2-} and organic carbon are the principal contributors to fine mass with NO_3^- being important on 2 days.

3.7.6.4 Relationships Among Optical and Chemical Species Data

A scattergram of 24-hour fine mass and SO_4^{2-} concentrations for all visibility monitoring sites is given in Figure 3-222. The data show a strong relationship between fine particles and SO_4^{2-} with a correlation of 0.86. There are a few fine particle concentrations in the 20 to 30 $\mu g/m^3$ range that correspond to relatively low SO_4^{2-} values. However, at the high concentration end for both fine mass and SO_4^{2-}, there is a very strong relationship. This graph demonstrates that SO_4^{2-} is a major contributor to atmospheric fine mass loading.

Nephelometers were operated continuously at four sites (510, 528, 572, and 570) in 1994. Nephelometers measure the B_{scat}, which is a component of overall light extinction and a measure of visual quality. Scatter diagrams of B_{scat} values and concentrations of fine particles and SO_4^{2-} were prepared to gain an understanding of the relationship between light scattering and aerosol concentration and composition. Figures 3-223 through 3-226 show scattergrams between 24-hour average B_{scat} and fine mass for the four monitoring sites that operated nephelometers. Figures 3-227 through 3-230 scattergrams for B_{scat} and SO_4^{2-}. The B_{scat} measurements are reasonably well correlated with both fine mass and SO_4^{2-} at the New York and Pennsylvania sites. The Ohio site shows correlations of close to 0.5 for both fine mass and SO_4^{2-}. The Sikes, LA site shows the poorest correlation. The Sikes monitor is frequently influenced by high humidity, which affects the B_{scat} measurements and confounds the correlation analysis. In any event, atmospheric optical properties as measured by light scattering are strongly influenced by fine aerosols, whose major component is SO_4^{2-}, at the three sites in eastern Ohio, Pennsylvania, and southwestern New York. This three-state region is downwind of the major SO_2 source region along the Ohio River. No conclusions can be made regarding the Sikes data.

3.7.6.5 Photographic Visual Quality

As a preliminary analysis of the relationship between visual quality and particle concentrations and composition, the record of 24-hour particle levels and photographs taken at Arendtsville in 1994 were examined. Two days were selected for presentation. November 10, 1994 had low fine mass and SO_4^{2-} levels. The fine mass value was 1.4 $\mu g/m^3$; and the SO_4^{2-} value was 1.5 $\mu g/m^3$. Figure 3-231 shows a photograph of the scenic view from the Arendtsville monitoring site. The visibility is quite good. The visual information content (contrast, color, line, and texture) of the scene is also good. Note the excellent view of the mountains in the background of the photograph. Contrast is evidenced by the image of the silo in the left side of the figure and by the peak on the right side. Good texture is shown in the details of the valley in the "middle" of the picture. Note the red barn on the right side. Obviously, the fine visibility and visual information content resulted from the very low particle and SO_4^{2-} concentrations. Afternoon B_{scat} values were low. Measured levels were about 0.02.

Figure 3-232 shows a photograph of the same view on July 31, 1994. The 24-hour fine mass concentration was 38.6 $\mu g/m^3$, and the SO_4^{2-} level was 24.1 $\mu g/m^3$. The visual quality and

visual information content is poor as evidenced by the significant haze in the photograph. B_{scat} levels averaged over 0.3. The relationship between high fine mass and SO_4^{2-} levels and poor visibility is obvious in this example.

3.7.6.6 Summary

An initial analysis of 1994 visibility-related measurements showed a strong relationship between atmospheric light scattering, visual quality, and fine particle concentrations. Fine particle levels peaked in the summer and were highly correlated with atmospheric fine SO_4^{2-}. In the winter, NO_3^- and organic carbon contributed to fine mass loadings. Light scattering (B_{scat}) increased as concentrations of fine particles and SO_4^{2-} increased. Photographs of scenic vistas showed excellent visual quality and content during periods of low fine particle and SO_4^{2-} concentrations and poor visual quality (e.g., dense haze) during periods of elevated fine mass and SO_4^{2-}.

3.8 Other Studies

3.8.1 Mobile Dry Deposition Program

EPA is sponsoring as part of CASTNet a study to measure directly dry deposition fluxes to better understand deposition processes and to evaluate and improve the MLM and other models. A mobile system for measuring directly dry depositions of O_3, SO_2, and HNO_3 was designed, built, and deployed at several sites since early 1994. The system, instrumentation, and sampling protocol are summarized in this section, along with a brief description of the several field studies.

Figure 3-233 provides a schematic of the measurement system components and instruments. Table 3-47 lists the measurements and methods of the system. Fluxes of O_3, SO_2, and CO_2 are measured by eddy correlation using fast response pollutant analyzers. The analyzers include a chemiluminescent O_3 instrument with a 4-hertz (Hz) sampling rate, a modified Meloy flame photometric SO_2 sensor with a 1-Hz sampling rate, and a LICOR 6262 sensor that measures H_2O and CO_2 at 5 Hz by differential absorption of infrared radiation. A sonic anemometer is used to measure the three components of wind for the eddy correlation calculations.

Nitric acid is measured at 1 and 8 m above ground level to provide a vertical gradient. HNO_3 is sampled over a 2-hour period using two filter packs. The HNO_3 gradient is converted to flux

by applying a heat exchange coefficient calculated from the sonic wind and temperature gradient measurements. An energy budget is also calculated for the purpose of evaluating the quality of the flux measurements (Finkelstein *et al.*, 1995). The energy budget is characterized by heat flux, latent heat flux, soil heat flux, soil storage, and net radiation.

Meteorological data are also collected continuously in a standard CDN configuration to provide input to the MLM. In addition, LAI and information on vegetation are collected weekly.

The DAS calculates eddy correlation fluxes of O_3, SO_2, CO_2, and H_2O, temperature, virtual temperature, and the three components of the wind in real time and outputs 30-minute averages continuously. Raw data files (10-Hz data for nine measures) are saved for 10 or more half-hour periods each day. The measurements undergo QA as described by Finkelstein *et al.* (1995). Post field processing includes converting units, removing suspect values, and MLM calculations of deposition velocities.

Initial site deployment took place over the winter of 1994 at an agricultural research station operated by North Carolina State University in Raleigh, NC. The terrain was gently rolling pasture land. Mixed grasses comprised the vegetation type. This installation served as a test and shake down period for the instrumentation.

In April 1994, the system was moved to Beaufort, NC, and deployed in a pasture on Open Ground Farms, near Site 142. Fluxes were measured above mixed grasses. The terrain was very flat with a fetch of over 5 km. The system remained deployed until July 1994, when it was returned to the QST Environmental office in Research Triangle Park, NC. Equipment modifications continued through the operation at Beaufort to improve flux measurement technique.

In August 1994, the system was moved to Bondville, IL, near Site 130. The terrain was flat with extensive fetch. Measurements were above corn plants approximately 8 feet tall. Fluxes of O_3, SO_2, CO_2, and water vapor were measured as well as heat flux parameters as the corn senesced. Nitric acid gradient sampling was also performed. Equipment remained operating during harvest, and flux measurements were continued above the bare field until the system was removed in October 1994.

From December 1994 through February 1995, the system was again deployed at North Carolina State University in Raleigh, NC, with limited operation. During this time, O_3 flux measurements were performed above grass and sometimes snow.

From April through May, 1995, the system was deployed at Sand Mountain, AL, several kilometers from Site 152. The terrain was gently rolling with grass vegetation. Cattle were grazing the pasture. Fluxes of O_3, SO_2, CO_2, and water vapor were measured. Heat flux, soil and plant conditions were also monitored. Fluxes of HNO_3 were determined by the gradient sampling method.

From June through October 1995, the system was deployed in a soybean field near Allenville, KY. The terrain was gently rolling. The equipment was installed 3 days after the beans were planted. Crop development was documented during the entire life cycle of the beans. LAI and porometer measurements were taken to characterize plant activity. Fluxes of O_3, SO_2, CO_2, and water vapor were taken as the beans developed and were harvested. Heat flux and soil conditions were also monitored. Empirical soil moisture samples were also collected to develop a calibration curve for the continuous soil moisture probes used in routine operation. Data collected during this field effort were made available as part of the Southeastern Consortium Intermediate Oxidant Network (SCION) oxidant study summer intensive program conducted near Nashville.

From April 1996 through May 1996, limited site operation commenced at Duke Experimental Forest in Chapel Hill, NC. Within the 2-km fetch, the terrain was mostly flat with planted pine vegetation. The main objective of this experiment was flux measurement comparison for precision purposes. Three sonic anemometers and fast O_3 analyzers, with two CO_2/water vapor analyzers, were deployed at the same height above the forest canopy. Applied Technology Incorporated (ATI) and Gill sonic anemometers were compared. After the precision flux measurements were taken, flux profiles above the canopy were measured with the three systems. Personnel from Duke University performed water vapor flux and plant physiology measurements during the same time period. During system operation, another experiment involving CO_2 enrichment, conducted by Brookhaven National Laboratory, proceeded. Experience with logistical difficulties while operating the flux measurement equipment above a

forest canopy was gained during this field effort, which proved to be very valuable for future installation situations.

From July 15, 1996, through August 15, 1996, the system was deployed in another bean field near Plymouth, NC. The terrain was flat. This effort was part of the Nitrous Oxidant precursor measurement technique and Validation Assessment program (NOVA, 1996) hosted by North Carolina State University. The experiment was attended by various flux measurement groups, including Argonne National Laboratory, National Aeronautics and Space Administration (NASA), University of Maryland, NCS, NOAA, and the National Center for Atmospheric Research (NCAR) as a technique comparison study. All parameters were measured as a routine complete system operation. An additional experiment designed to measure particle flux with a laser particle counter was also conducted.

From August 1996 through October 1996, the system was deployed at Rutgers University Marine Research Field Station in Tuckerton, NJ. The surface of interest during this effort was the estuary water. Equipment was installed on an existing tower previously used for communication by the U.S. Coast Guard. During high tide, water was present at the base of the tower. At low tide, the marsh grass was exposed. Fluxes of O_3, SO_2, CO_2, and water vapor were measured combined with HNO_3 gradient samples. A fiber optic data link was employed to transmit the sensor and analyzer output from the tower to the computers located seven hundred feet away in the equipment trailer. Some of the methods for operation pioneered at the earlier experiment in Duke Forest were refined for improved operation under extremely harsh conditions encountered in the marine environment.

Planned operation for 1997 will include measurements above a deciduous forest canopy. Approximately 70 percent of the sensitive ecosystems are forested, making it an important environment for deposition study. It is anticipated that more complex terrain will also be involved during future site operation. Instrument development and modification continue to improve operation and reliability, including operation of a new design fast O_3 analyzer.

An EPA investigation (Clarke, 1997) is using the data collected from the mobile monitoring system to better understand deposition processes and to evaluate and refine the MLM. Results from these studies will be published elsewhere.

3.8.2 Comparison of Filter Pack and Annular Denuder Samplers

CASTNet uses a three-stage filter pack sampler to measure concentrations of acid gases and aerosols. Because of various concerns expressed in the literature about the efficacy of filter pack sampling, EPA is sponsoring a study to compare measurements taken with filter pack samplers to measurements taken with annular denuders and also with SO_2 and HNO_3 continuous analyzers. The study is also addressing the utility of using cyclones for removing large particles from the air sampling stream as a means of improving the measurements.

The study so far includes 10 months of collocated collection of weekly denuder and filter pack samples at 11 CASTNet sites (Figure 3-234). At two sites (133 and 147), cyclones were also tested. At three separate sites, continuous analyzers are operated to measure low-level (i.e., low concentrations) of SO_2 and NO_x. A NO_x analyzer is operated with three channels to separate NO_x, HNO_3, and NO_3^-. Preliminary results have been reported by ESE (1997). The study will continue through August 1997 with a final report scheduled in November.

The results to date show a high correlation between SO_4^{2-} measurements from the filter pack and annular denuder system. HNO_3 measurements on the filter packs are higher than the denuder values (e.g., 11 to 12 percent higher at Site 133). SO_2 concentrations measured by the filter pack and annular denuder system show very little difference (Figure 3-235). These results are considered preliminary and may change with a more complete analysis of the data.

Chapter 4
Summary

4.1 CASTNet Operations

EPA initiated regional measurements of acid gases and aerosols and supporting meteorological data in 1986 through the NDDN. Field measurements began in 1987, and more than 80 percent of the network was operational in 1989. NDDN was incorporated into CASTNet in 1991. Chapter 2 summarizes the history of the network. Currently, CASTNet operates 45 eastern sites and 3 western sites and 21 sites that measure precipitation chemistry.

The CASTNet sites were selected to characterize regionally representative air quality. Major sources of SO_x and NO_x were avoided to reduce the likelihood of measured concentrations being influenced by individual plumes or groups of sources. In addition, the land use near each station was selected to match, as much as possible, the predominating regional land use in order to make use of the meteorological data to model representative deposition velocities and fluxes.

QST has developed a substantive infrastructure involving field operations, laboratory operations, and data management. The QST infrastructure has resulted in an efficient system that covers the process of taking the measurements through delivering the data to EPA.

CASTNet is served by a strong QA/QC program. EPA established rigorous goals for the accuracy and precision of the field and laboratory data. The CASTNet data largely meet the stated precision and accuracy objectives. In short, the CASTNet data constitute an exceptional database for the purpose of discerning status and trends in air quality and of supporting other scientific activities.

The results from the QA/QC program demonstrate conclusively that the observed changes in concentrations and depositions discussed in this report are real and not the result of network modifications or of data imprecision or inaccuracy. Concentration and deposition changes are the result of changes in emissions and of meteorological fluctuations, not of changes in the network.

4.2 Concentrations

Concentrations of pollutant gases and aerosols are presented and discussed for various averaging periods. Annual averages of SO_2 and SO_4^{2-} reflect the geographic distribution of sources of SO_2. Peak concentrations are observed in and downwind of the major source regions. Sharp concentration gradients are observed along the peripheries of the network. SO_2 concentrations are highest in the winter, whereas SO_4^{2-} levels are highest in summer, reflecting significant photochemical activity in the summer months. Weekly average concentrations show significant week-to-week variability superimposed on the seasonal cycles.

The pattern of annual NO_3^- levels is not as well correlated with the geographic distribution of NO_x emissions as was SO_2 and SO_4^{2-}. Evidently, the agricultural use of NH_3 influences NO_3^- aerosol formation as much as the distribution of NO_x sources. Annual HNO_3 concentrations are lower along the Appalachian chain, reflecting loss processes induced by the presence of complex terrain. Annual levels of total NO_3^- are lower generally in the southeast despite the fact that NO_x emissions are about the same as in the midwest, the area with the highest observed NO_3^- levels. HNO_3 concentrations are higher in the summer throughout CASTNet. Total NO_3^- levels show little seasonal variability.

CDN data show regional variability in aerosol speciation and acidity as well as concentration. The relationship between NH_4^+ and SO_4^{2-} (molar basis) based on annual values for 1991 give an indication of the amount of neutralization of the acidic SO_4^{2-} aerosol. On the whole, the data suggest that aerosol acidity is greater at forested sites than at agricultural sites. Ammonium is the predominant neutralizing cation with metal cations playing an insignificant role except at a few midwestern sites and sites near the coast.

The CASTNet measurements show statistically significant reductions in annual SO_2, SO_4^{2-}, and HNO_3 concentrations averaged over all eastern sites. The data for the eastern sites combined show a 23-percent reduction in SO_4^{2-} and a 43-percent reduction in SO_2 between 1989 and 1995 annual concentrations. These decreases do not account for the year-to-year variations in concentrations between 1989 and 1995 and may not appear as large when the variations are taken into account. Changes in sulfur species are more pronounced in the four northern subregions and smaller, but still substantial, in the two southern subregions. There is no apparent trend in the data from the western sites. The eastern data indicate about 70 percent of ambient sulfur is in the form of SO_2.

SO_2 concentrations show significant reductions in summer and winter seasons, even though concentrations are much higher in winter and concentrations are more directly related to emissions in the colder months.

The trend in summer average SO_4^{2-} levels explains the decline in annual averages. Extending the trend analysis by including the 1978 SURE measurements reinforces the demonstration of a significant downward trend in SO_4^{2-}.

The slight reduction in HNO_3 concentrations results from the decline in summer averages. The downward trend is observed in all of the subregions, except for the southern periphery and the west. No trends are observed in annual concentrations of NO_3^- aerosol and total NO_3^-.

The trend analyses presented herein are based on straightforward linear regressions. They do not attempt to explain the causes of the downward trends. However, the percent reductions in sulfur species are larger than can be explained by typical yearly meteorological variability. The logical conclusion is a significant relationship between the downward trend in concentrations and the reported reductions in SO_x emissions. In any event, EPA investigators are pursuing advanced statistical models of the trends in concentrations which will be published elsewhere.

4.3 Dry Depositions

The MLM was used to simulate deposition velocities of gases and aerosols using CDN meteorological, land use, and vegetation data as input. Hourly deposition velocities were calculated from the measurements and data. Except for O_3, the hourly deposition velocities were averaged to obtain weekly average deposition velocities. Estimates of the uncertainties in the simulated deposition velocities suggest the MLM results tend to underestimate observed deposition velocities for SO_2 and O_3, especially daytime values during periods of plant growth. The results for HNO_3 and aerosols suggest the uncertainty is higher. Extrapolation of deposition velocities from a specific CASTNet site to other locations should be done with caution, especially in areas of complex terrain.

Weekly average concentrations were combined with weekly deposition velocities to calculate weekly average dry depositions (fluxes). The deposition data were then averaged to obtain annual and seasonal averages. Maps of annual fluxes of total sulfur are discussed in Chapter 3.

The distributions of annual dry sulfur depositions are similar from year to year and correspond well with the maps of SO_2 and SO_4^{2-} concentrations and reflect the distribution of SO_x sources. Annual fluxes of total nitrogen show a fairly uniform pattern of depositions above 2.0 kg/ha (as N) from year to year. Lower depositions were calculated for the CDN sites in the Appalachian chain, similar to the results for HNO_3 concentrations.

Time series of weekly fluxes show considerable site-by-site and weekly variability. The seasonal cycles of fluxes of individual species are similar to the seasonal behavior of concentrations. Scattergrams and correlation statistics show a strong relationship between concentrations and depositions of SO_2, SO_4^{2-}, and HNO_3 measured in 1995.

Linear regressions were calculated for annual depositions of SO_2, SO_4^{2-}, total sulfur, HNO_3, NO_3^-, and total NO_3^- (as N) from 1989 through 1995 for all the eastern sites combined. Downward trends are indicated for the sulfur species although the trend lines are not considered statistically significant. The downward slopes for SO_2 and total sulfur are greater than for SO_4^{2-}, consistent with the results for concentrations. The data show a 29-percent reduction in deposition of SO_2 (as S) and only a 6-percent reduction in deposition of SO_4^{2-} aerosol. These percentage reductions in depositions are lower than the comparable reductions in concentrations.

The linear regressions show no significant trends in depositions of the nitrogen species. Depositions of sulfur and nitrogen species calculated for the western sites exhibit no trends.

4.4 Concentrations in Precipitation

Concentrations of anions and cations were measured in precipitation samples collected at CASTNet sites and those NADP sites approximately collocated with CDN sites that do not collect precipitation samples. The CDN and NADP data were combined to form one concentration and wet deposition database. Geographic patterns of concentrations (in precipitation) of SO_4^{2-}, NO_3^-, and pH show some yearly variability while, at the same time, reflect the distribution of major sources of SO_x and NO_x in the eastern United States. Summer average concentrations of SO_4^{2-} and NO_3^- in precipitation are higher and more variable than corresponding winter values. Correlation analyses show a strong relationship between pH and SO_4^{2-} levels and a reasonable relationship between pH and NO_3^-. Annual SO_4^{2-} concentrations

exhibited statistically significant downward trends for the upper northeast and southern periphery subregions. Although the eastern region did not exhibit a statistically significant reduction, a downward trend is indicated by the data and analyses.

4.5 Wet Depositions

Wet deposition rates were calculated from the combined CASTNet and NADP database. Patterns of wet SO_4^{2-} depositions suggest an overall reduction in depositions between 1990 and 1994. In general, wet depositions decreased at a faster rate than concentrations.

Linear regressions of annual wet depositions of SO_4^{2-} (as S) show statistically significant downward trends for all the eastern sites combined. The results show an overall decrease in wet SO_4^{2-} deposition of approximately 35 percent over the period 1989 to 1995.

No significant trends were indicated for wet NO_3^- depositions. However, the measurements still show a reduction of about 20 percent for the eastern data combined over the 7-year period even though the results are not considered statistically significant.

4.6 Total Deposition

Dry and wet depositions were summed to obtain total depositions of sulfur and nitrogen species. Patterns of annual total depositions of sulfur again reflect the distribution of SO_x sources and the prevailing winds across the eastern United States. The percentages of total deposition that are in the form of dry deposition show significant geographic variability. The range in percentages varies from 14 to 60 percent. Dry deposition is a more significant contributor in and near the major source region. In areas with heavy precipitation, wet deposition is much more important. The estimates of dry deposition percentages are probably low given the uncertainties in modeled deposition velocities.

The percentages of total nitrogen that occur as dry deposition are significant. Most of the sites show a contribution of 40 percent or more. Again, the percentages are relatively lower in areas of high terrain and areas with heavy rainfall. The percentages are also lower at the remote sites.

The total deposition data show statistically significant reductions in annual deposition of sulfur over the period 1989 through 1995. The downward trends are considered significant throughout the eastern network, except for the upper midwestern sites. No trend is apparent in the western data.

Estimates of total deposition of nitrogen species exhibit no trend.

4.7 Ozone

The CDN O_3 data provide estimates of exposure statistics and allow gauging compliance with the NAAQS for O_3. During the summer of 1988, several sites measured concentrations above the 1-hour standard of 125 ppb. After 1988, violations of the NAAQS were limited to sites in the Washington-New York corridor. Concentrations above the new 8-hour standard of 85 ppb (3-year average of the fourth highest, daily running 8-hour average in each year) were measured throughout the midwest and northeast subregions.

The measure SUM06 had been suggested as a secondary standard for O_3. A majority of CDN sites show SUM06 values consistently above 25 ppm-hr, the proposed numerical limit. Another proposed measure W126 shows more geographic variability with fewer sites measuring values above 25 ppm-hr.

The O_3 measurements show significant geographic differences which are influenced by a variety of atmospheric processes (e.g., boundary layer effects, day-night differences in photochemistry, and scavenging and dry deposition). For example, mountaintop sites show little diurnal variability and experience high exposure because of the locations of these sites above ground-based inversions and their isolation from deposition processes and scavenging by nighttime NO_x emissions. On the other hand, suburban sites show large diurnal variability, high short-term concentrations, and lower exposure statistics.

4.8 Synopsis of CASTNet Measurements

A synopsis of CASTNet measurements for the 7-year period (1989 to 1995) is given in Table 4-1. The table provides means and coefficients of variation for six air quality measures. Overall means and CDN subregional and seasonal averages are provided. Results are given for ambient concentrations, deposition velocities, dry deposition fluxes, and wet depositions. Certain calculated ratios are also provided. The averages were calculated from annual (or seasonal) averages for the group of CDN sites operating in each of the 7 years (seasons). The dry and wet fluxes are given in terms of sulfur and nitrogen. Annual fluxes are given in units of kg/ha per year. Seasonal fluxes are given in units of kg/ha per season. The sum of four seasonal fluxes equals the annual flux. The coefficients of variation represent combined annual (seasonal) - geographic variability.

The data in Table 4-1 reinforce the discussions in Sections 4.2 through 4.7. The precursor gas SO_2 shows generally more variability than the reaction products like SO_4^{2-} aerosol and the gas HNO_3. One exception is the annual coefficient of variation for NO_3^- aerosol, which is explained by the fact that NO_3^- formation is influenced by NO_x emissions and NH_3 usage. Concentrations and dry depositions are more variable than deposition velocities. Dry fluxes are more variable than wet fluxes.

Extremes in the measurements were generally observed in the summer and winter, while values more typical of CASTNet averages were observed in spring and fall. Peak concentrations and dry depositions of SO_4^{2-}, O_3, and HNO_3 were observed in summer. Peak concentrations and dry depositions of SO_2 were observed in winter. Maximum values of wet deposition of sulfur and nitrogen were observed in summer and minimum values in winter.

The ratios in Table 4-1 show the importance of SO_2 and HNO_3 in contributing to the dry deposition of sulfur and nitrogen, respectively. The ratios show the importance of the contribution of dry deposition processes to total deposition of sulfur and nitrogen, especially considering that dry deposition fluxes represent lower bound estimates.

4.9 Mountain Cloud Deposition Program

MADPro is a component of CASTNet designed to study over several years the deposition of air pollutants to high elevation forests. MADPro objectives are to measure cloud chemistry, determine total deposition, and define source regions which impact high elevation ecosystems in the eastern United States. MADPro has been in operation since 1994 at a few high elevation sites. The results to date show that cloudwater can be the primary pathway for deposition of pollution. MADPro results have been presented in annual reports for 1994, 1995, and 1996. Work has begun on modeling the various deposition pathways at these high elevation sites.

4.10 Visual Air Quality

An initial analysis of visual air quality measurements taken in 1994 was discussed. The data show a strong relationship between atmospheric light scattering, visual quality, and fine particle concentrations. Fine particle levels peaked in the summer and were highly correlated with fine atmospheric SO_4^{2-}. In the winter, NO_3^- and organic carbon contributed to fine mass loadings. Annual averages of fine mass concentrations are below the proposed NAAQS of 15 $\mu g/m^3$. Light scattering increased as concentrations of fine particles and SO_4^{2-} increased. Photographs of scenic vistas showed excellent visual quality and content during periods of low fine particle and SO_4^{2-} concentrations and poor visual quality during periods of high concentrations.

4.11 Other Studies

EPA is sponsoring a series of field studies to measure directly dry deposition fluxes over a variety of land use and terrain settings to better understand deposition processes and to evaluate and improve the MLM and other models. Fluxes of SO_2 and O_3 are measured by eddy correlation. HNO_3 flux is estimated by measuring the vertical gradient of HNO_3 concentrations. The flux measurement system is supported by meteorological measurements and a DAS. The mobile system has been used since 1994 to collect data at several sites. The resulting extensive database is being used by EPA investigators to evaluate and improve MLM. The results will be published elsewhere.

CASTNet includes an intercomparison study between annular denuders and filter packs. The results to date show a high correlation between SO_4^{2-} measurements using the two measurement systems and similar results for SO_2. HNO_3 measurements on the filter packs are higher than the denuder values. These results are considered preliminary while awaiting additional analyses.

4.12 Data Completeness

This section provides an overview of the data completeness rules used for the various analyses presented in this report.

4.12.1 Filter Pack Concentrations

The percent completeness statistics for filter pack concentration data for all CDN sites for years 1987 through 1995 are presented in Table 4-2. To be included in the 6-year average maps (1989 to 1994), sites were required to have data for 5 of the 6 years with a 75-percent completeness. In most cases, completeness exceeded 90 percent. This same requirement was used in creating the single year plots for 1989, 1992, and 1994 (Figures 3-1 through 3-26).

Requirements for the sites used in the quarterly plots (Figures 3-27 and 3-28) were 70-percent completeness per quarter. A 70-percent completeness rule was also used in selecting the sites for the summer versus winter plots (Figures 3-29 through 3-40).

For Figures 3-42 and 3-43, the completeness requirement was 70 percent annually from 1989 through 1995. The only exceptions to this rule were Sites 151, with a 67-percent completion rate in 1992, and Sites 114, 115, 123, and 135 with 69-, 56-, 69-, and 67-percent completeness rates, respectively, in 1995. These lower completion rates were due to the shutdown during the fourth quarter.

Although a 50-percent completeness rate (i.e., 26 weeks) is specified on Tables 3-1 through 3-3, there are only a handful of sites that fall below a 70-percent completion rate. These sites, listed by year, are:

1987	Site 120	58 percent	1992	Site 151	67 percent
1988	Site 109	50 percent	1993	Site 103/104	69 percent
	Site 128	50 percent		Site 164	67 percent
1989	Site 111	58 percent	1994	Site 145	60 percent
	Site 161	63 percent		Site 175	58 percent
	Site 162	67 percent	1995	Site 114	69 percent
	Site 163	58 percent		Site 115	56 percent
	Site 164	58 percent		Site 123	69 percent
	Site 167	65 percent		Site 135	67 percent
	Site 169	63 percent		Site 138	67 percent

The data used to produce these tables were also used to generate the regression plots in Figures 3-44 through 3-48.

4.12.2 Filter Pack Deposition Velocities and Fluxes

Completeness percentages for all CDN sites by region for calculation of deposition velocities and fluxes for the years 1987 through 1995 are presented in Table 4-3. The rules used for calculation of V_d were as follows:

1. Seasonal averages — For calculation of seasonal averages by site, a season was required to have at least 8 non-missing weeks (62-percent completion rate) to be valid. If a season had less than 8 non-missing weeks, the seasonal V_d was set to missing. For seasons with 8 or more non-missing weeks, the non-missing values were averaged by season.
2. Annual averages — For calculation of annual averages by site, a year was required to have at least 3 non-missing seasonal averages to be valid. If a year had less than 3 non-missing seasons, the annual V_d was set to missing. For years with 4 non-missing seasons, the seasonal V_ds were averaged. For years with 3 non-missing seasons, the non-missing seasonal V_ds were averaged.
3. Regional statistics — For calculation of regional statistics, the site averages for the period in question (e.g., annual, seasonal) were averaged.

The rules used for calculation of fluxes were as follows:

1. Seasonal sums — For calculation of seasonal sums by site, a season was required to have at least 8 non-missing weeks to be valid. If a season had less than 8 non-missing weeks, the seasonal flux was set to missing. For seasons with 8 or more non-missing weeks, the non-missing values were averaged by season and then multiplied by 13.
2. Annual sums — For calculation of annual sums by site, a year was required to have at least 3 non-missing seasonal sums to be valid. If a year had less than 3 non-missing seasons, the annual flux was set to missing. For years with 4 non-missing seasons, the seasonal fluxes were summed. For years with 3 non-missing seasons, the non-missing seasonal fluxes were averaged and then multiplied by 4.
3. Regional statistics — For calculation of regional statistics, the site values for the period in question (e.g., annual, seasonal) were averaged.

These above rules were followed to produce Tables 3-7 through 3-11, Figures 3-52 through 3-62, and Figures 3-83 through 3-88. The five sites used in Figures 3-63 through 3-83 all apply to this rule except for Site 137. Table 4-3 shows this site with two missing seasons in 1995. However, since these figures are plotted on a weekly basis for 1995, and inclusion of a high elevation site was desired for these comparisons, the site was used as the annual completeness rate of 73 percent (using number of weeks with deposition values in 1995) was sufficient to illustrate the desired comparisons between concentrations, V_ds, and fluxes.

4.12.3 Precipitation Concentrations and Depositions

Quarterly completeness percentages for all CDN wet deposition sites from 1989 through 1995 are presented in Table 4-4. All CDN precipitation sites plotted on the maps in Figures 3-89 through 3-106 and 3-135 through 3-145 had annual completeness rates of 85 percent or greater. The sites used (Sites 114, 126, 128, 161, and 167) for the quarterly time series plots in Figures 3-107 through 3-118 and 3-151 through 3-155 were required to have quarterly completeness of 8 out of 13 weeks, or 62 percent, in order for a quarterly average to be plotted. As shown in Table 4-4, however, rates this low were the exception for these sites. The seasonal plots in Figures 3-119 through 3-124 and 3-146 through 3-150 also required the selected sites to have 62-percent completeness for the season. The only instances completeness rates were this low for a season occurred for winter 1995 during the shutdown period. For a precipitation site to be included in the regression analyses (Figures 3-127 through 3-134 and 3-156 through 3-160), a site was required to have an annual completeness rate of 70 percent.

4.12.4 Rolling 8-hour Ozone Concentrations

Annual fourth-highest daily maximum 8-hour O_3 concentrations were calculated for all available CASTNet data according to the data handling conventions and computational standards outlined in Appendix I of 40 CFR Part 50. Methods and calculations are summarized below.

The months comprising the O_3 season vary by state (40 CFR Part 50). All available records for each site/year/season were selected and processed. Completeness was determined by comparing the number of valid records to the total possible days for each site/season. These values are presented in Table 4-5.

Averages were calculated for each available consecutive 8-hour block of ozone monitoring data. Averages, in ppb, were assigned to the beginning hour of each period. Blocks with fewer than 6 valid hours were considered valid only if, after substituting 0.001 ppb for missing values, the average exceeded the standard. Values were truncated to three decimal places.

Daily maxima were calculated for all days with 18 or more valid hours. Days with fewer than 18 valid hours, but a maximum exceeding the standard were also considered valid.

The fourth-highest annual daily maximum value was selected for all sites with at least 75 percent of O_3 season days having valid daily maximum values. In addition, years with fewer than 75 percent valid hours but fourth-highest values exceeding the standard were considered valid.

Data completeness criteria were first applied to establish the validity of the period for each site. Guidance includes exclusions for sites with less than 75-percent complete annual O_3 season data; these exclusions require overview by a Regional EPA Administrator and were not applied for this analysis. Criteria are, in general, 75-percent completeness for each year and 90-percent completeness for the period. Fourth-highest annual daily maxima were averaged for each site meeting completeness criteria. Values were rounded to two decimal places, with thousands of 5 and greater rounding up. Rounded values of 0.09 (ppb) and greater were flagged as exceeding the primary standard.

Chapter 5
Conclusions and Recommendations

5.1 Conclusions

CASTNet data precision and accuracy meet the EPA objectives. CASTNet data constitute an exceptional database for understanding regional air quality and for supporting other scientific activities.

CASTNet measurements collected over the period 1989 to 1995 are able to detect trends in concentrations of acid gases and aerosols. Although the following results do not account for variations in meteorology from year to year, concentration data still show statistically significant reductions in annual SO_2, SO_4^{2-}, and HNO_3 levels. The eastern data show a 23-percent reduction in SO_4^{2-} and a 43-percent reduction in SO_2 between 1989 and 1995. Extending the trend analysis by including the 1978 SURE measurements reinforces the demonstration of a significant downward trend in SO_4^{2-}. The eastern data indicate about 70 percent of ambient sulfur is in the form of SO_2.

The percent reductions in sulfur species are larger than can be explained by meteorological variability. There is an apparent relationship between reductions in concentrations and reported reductions in emissions.

Concentration data show a slight decline in HNO_3 levels. No trends are observed in annual concentrations of NO_3^- aerosol and total NO_3^-. HNO_3 contributes about 65 percent of ambient nitrogen throughout the network.

Data collected in the western network exhibit no trends.

Estimates of the uncertainties in deposition velocities suggest the MLM results tend to underestimate observed V_d (and consequently fluxes) for SO_2 and O_3. The uncertainty in V_d for HNO_3 and aerosols is higher. Calculated dry depositions consequently represent lower bound estimates and do not account for quantified modeled uncertainties.

Calculated annual fluxes show downward trends for the sulfur species although the trend lines are not considered statistically significant. The eastern data show a 29-percent reduction in deposition of SO_2 (as S) and only a 6-percent reduction in deposition of SO_4^{2-}. The calculated reduction in total sulfur deposition is 27 percent. The eastern data indicate about 85 percent of sulfur deposition is in the form of SO_2.

No trends are apparent for the eastern nitrogen fluxes or in the depositions calculated for the western sites.

Concentrations in precipitation of SO_4^{2-}, NO_3, and pH show extensive spatial variability. Precipitation concentrations of annual SO_4^{2-} measured between 1989 and 1995 show significant reduction for two subregions. Although the regression results for all eastern CDN and NADP sites combined are not significant, a downward trend is indicated. Linear regressions of annual NO_3 concentrations observed in precipitation show no significant trends.

Sulfate wet depositions (combined CDN/NADP database) averaged over the eastern sites show a 35-percent reduction over the period 1989 to 1995. The results are considered statistically significant.

Nitrate wet depositions show about a 20-percent reduction over the 7-year period although the results are not considered statistically significant.

Estimates of total deposition show significant reductions in annual sulfur deposition for the eastern sites combined over the period 1989 to 1995. No trend is evident in total depositions of nitrogen.

O_3 data show that 8-hour concentrations above the proposed primary NAAQS were measured throughout most of the eastern network.

A majority of sites show SUM06 values consistently above 25 ppm-hr, the proposed numerical limit.

The O_3 measurements show significant geographic differences which are influenced by terrain effects, atmospheric boundary layer scavenging and photochemistry.

The results to date from the MADPro show that cloudwater can be the primary pathway for deposition of pollutants at high elevation sites.

Visual air quality data show a strong relationship between light scattering, visual quality, and fine particle concentrations. Fine particles peaked in summer and were correlated with fine SO_4^{2-} levels.

Light scattering increased as concentrations of fine particles and SO_4^{2-} increased. Photographs of scenic vistas showed excellent visual quality and content during periods of low fine mass and SO_4^{2-} levels and the opposite during periods of high concentrations.

Annual concentrations of fine particles (<2.5 μm in diameter) are below the proposed NAAQS of 15 $\mu g/m^3$.

5.2 Recommendations

CASTNet should be operated with minimum disruptions to continue the appropriate database and allow for various analyses, including status and trends.

The number of CDN sites and site locations should be reviewed to optimize site locations for improvement in the several displays and analyses.

The MLM should continue to be evaluated and improved to reduce the uncertainties and improve the precision in the estimates of dry deposition. Model acceptance criteria should be developed.

The mobile dry deposition field studies should continue until the MLM is fully evaluated and flux calculations are representative of a wide variety of land use and terrain settings.

Advanced statistical analyses need to be performed on the CASTNet data to elucidate the apparent trends and decipher trends not apparent from the simple linear regressions.

Statistical analyses should investigate trends at individual sites as well as subregional averages in order to better understand the response to changes in emissions and meteorological fluctuations.

RADM simulations should be performed as diagnostic tools to better explain the effects of photochemistry and precipitation scavenging on dry and wet deposition.

The visual air quality data collected throughout the visibility network should be analyzed more thoroughly, including the use of absorbance data analyzed from the Teflon® filters. The absorbance data combined with the light scattering data provide an estimate of total light extinction.

The visibility network should be continued and perhaps expanded to detect trends in visibility-related air quality parameters.

MADPro data should continue to be analyzed to model the cloudwater pathway of deposition at high altitude locations.

CASTNet has produced an exceptional database that satisfies many of the requirements of the CAAA of 1990. The network will help assess compliance with the proposed NAAQS for O_3 and fine particles and gauge progress toward attainment. It will continue to measure improvements in air quality and depositions associated with CAA-mandated reductions in SO_x, NO_x, and VOC emissions over the next 10 years.

References

Anderson, J.R., Hardy, E.E., Roach, J.T., and Witmer, R.E. 1978. *A Land Use and Land Cover Classification System for Use with Remote Sensor Data.* U.S. Geological Survey Circular 671. Geological Survey Professional Paper 964.

Air Resource Specialists, Inc. 1994. Site Selection for Optical Monitoring Equipment (IMPROVE Protocol) Standard Operating Procedures.

Baumgardner, R.E., Kronmiller, K.G., Anderson, J.B., Bowser, J.J., and Edgerton, E.S. 1997. Development of an Automated Cloudwater Collection System for Use in Atmospheric Monitoring Networks. *Atmos. Environ.* Vol. 31.

Chamberlain, A. C. and Chadwick, R. C. 1953. Deposition of airborne radioiodine vapor. *Nucleonics* 8:22-25.

Chason, J., Huston, M., and Baldocchi, D. 1990. *A Comparison of Direct and Indirect Methods for Estimating Forest Canopy Leaf Area.* Environmental Sciences Division. Oak Ridge National Laboratory. Oak Ridge, TN.

Clarke, J.F., and Edgerton, E.S. 1993. *Dry Deposition Flux Calculations for the National Dry Deposition Network.* Prepared for the U.S. Environmental Protection Agency, Atmospheric Research and Exposure Assessment Laboratory. Research Triangle Park, NC.

Clarke, J.F., Ellestad, T.G., Finkelstein, P.L., Edgerton, E.S, and Bowser, J. 1995. *Design and implementation of a transportable system for direct measurement of dry deposition fluxes.* Proceedings, 11th Symposium on Boundary Layer and Turbulence, Charlotte, NC.

Clarke, J.F., Edgerton, E.S., and Martin, B.E. 1997. Dry Deposition Calculations for the Clean Air Status and Trends Network. *Atmos. Environ.* 31:3667.

Dennis, R.L., McHenry, J.N., Barchet, W.R.; *et al.* 1993. Correcting RADM's sulfate underprediction: Discovery and correction of model errors and testing the corrections through comparisons against field data. *Atmos. Environ.* 27A:975-997.

Eager, C., and Adams, M.B., (Ed.) 1992. *Ecology and Decline of Red Spruce in the Eastern United States.* Springer-Verlag Ecological Series 96:395-411.

Environmental Science & Engineering, Inc. (ESE). 1990a. *National Dry Deposition Network (NDDN) Field Operations Manual.* Prepared for U.S. Environmental Protection Agency (EPA). Contract No. 68-D2-4451. Gainesville, FL.

Environmental Science & Engineering, Inc. (ESE). 1990b. *National Dry Deposition Network (NDDN) Laboratory Operations Manual.* Prepared for U.S. Environmental Protection Agency (EPA). Contract No. 68-D2-4451. Gainesville, FL.

References (continued)

Environmental Science & Engineering, Inc. (ESE). 1991a. *National Dry Deposition Network (NDDN) Data Management Manual.* Prepared for U.S. Environmental Protection Agency (EPA). Contract No. 68-D2-4451. Gainesville, FL.

Environmental Science & Engineering, Inc. (ESE). 1997. *Comparison of CASTNet Filter Pack and Annular Denuder Samplers - Interim Data Report (October 1996 - February 1997).* Draft Report. Prepared for U.S. Environmental Protection Agency (EPA). Contract No. 68-D2-4451. Gainesville, FL.

Falconer, R.E. and P.D. Falconer. 1980. Determination of cloudwater acidity at a mountain observatory in the Adirondack Mountains of New York State. *Journal of Geophysical Research* 85C:7465-7470.

Gerber, H. 1984. Liquid water content of fogs and hazes from visible light scattering. *Journal of Climatology and Applied Meteorology* 23:1247-1252.

Heisler, S. *et al.* 1990. *Acid Model Operational Diagnostic Evaluation Study (Acid MODES) and Operational Evaluation Network (OEN).* ENSR. Glastonbury, CT 06033.

Hicks, B.B., Baldocchi, D.D., Hosker, R,P., Jr., Hutchison, B.A., McMillen, R.T., and Satterfield, L.C. 1985. *On the Use of Monitored Air Concentrations to Infer Dry Deposition (1985).* NOAA Technical Memorandum ERL ARL-141. 66 pp.

Hornbeck, J.W., and R.B. Smith. 1985. Documentation of red spruce decline. *Canadian Journal of Forest Research,* pp.1199-1201.

Hosker, R.P., Jr. and Womack, J.D. 1986. *Simple Meteorological and Chemical Filter Pack Monitoring System for Estimating Dry Deposition of Gaseous Pollutants.* In: Proceedings of the 5th Annual National Symposium on Recent Advances in the Measurement of Air Pollutants, Raleigh, NC, 14-16 May 1985, EPA/600/8-85/029 (available from NTIS, Springfield, VA), pp. 23-29.

James, K.O.W. 1993. *1991 Quality Assurance Report, NADP/NTN Deposition Monitoring.* Office of Atmospheric Chemistry. Illinois State Water Survey. Champaign, IL.

Lefohn, A.S. and Runeckles, V.C. 1987. Establishing a Standard to Protect Vegetation-Ozone Exposure/Dose Considerations. *Atmos. Environ.* 21:561-568.

Lefohn, A.S., Laurence, J.A., and Kohut, R.J. 1988. A Comparison of Indices that Describe the Relation Between Exposure to Ozone and reduction in the Yield of Agricultural Crops. *Atmos. Environ.* 22:1229-1240.

Li, Z. and V.P. Aneja. 1992. Regional analysis of cloud chemistry at high elevations in the eastern United States. *Atmos. Environ.* 26A:2001-2017.

References (continued)

Li-Cor, Inc. 1989. *LAI-2000 Plant Canopy Analyzer--Technical Information.* LI-COR, Inc., 4421 Superior Street, Lincoln, NE.

Lindberg, S.E., Silsbee, D., Schaefer, D.A., Owens, J.G., and Petty, W. 1988. *A Comparison of Atmospheric Exposure Conditions at Low- and High-Elevation Forests in Southern Appalachian Mountain Range*, pp. 321-344. In: M.H. Unsworth and D. Fowler, eds. Acid deposition at High Elevation Sites, NATO ASI Series C:Vol.252, Klumer Publ., Boston.

McLaughlin, S.B., C.P. Anderson, N.T. Edwards, W.K. Roy and P.A. Layton. 1990. Seasonal patterns of photosynthesis and respiration of red spruce saplings from two exevations in declining Southern Appalachian Stands. *Canadian Journal of Forest Research* 20:485-495.

McLaughlin, S.B., C.P. Anderson, P.J. Hanson, M.G. Tjoelker and W.K. Roy. 1991. Increased park respiration and calcium deficiency of red spruce in relation to acidic deposition at high elevation Southern Appalachian Mountain sites. *Canadian Journal of Forest Research* 21:1234-1244.

McMillen, R.T. 1990. *Estimating the Spatial Variability of Trace Gas Deposition Velocities.* NOAA Tech. Memo. ERL ARL-181, 37 pp.

Meyers, T.P. and Yuen, T.S. 1987. An Assessment of Averaging Strategies Associated with Day/Night Sampling of Dry-Deposition Fluxes of SO_2 and O_3. *J. Geophysic Res.* 92: 6705-6712.

Meyers, T.P., Hicks, B.B., Hosker, R.P., Womack, J.D., and Satterfield, L.C. 1991. Dry deposition inferential measurement technique-II seasonal and annual deposition rates of sulfur and nitrate. *Atmos. Environ.* 25A(10): 2361-2370.

Mohnen, V.A. and J.A. Kadlecek. 1989. Cloud chemistry research at Whiteface Mountain. *Tellus* 41B:79-91.

Mohnen, V.A. and R.J. Vong. 1993. A climatology of cloud chemistry for the eastern United States derived from the Mountain Cloud Chemistry Project. *Environ. Reviews* 1:38-54.

Mueller, P. and Hidy, G. 1983. *The Sulfate Regional Experiment: Report of Findings, Vols. 1 and 2.* EPRI. Palo Alto, CA. EPRI EA-1901.

Pierce, L.L. and Running, S.W. 1988. Rapid Estimation of Coniferous Forest Leaf Area Index Using a Portable Integrating Radiometer. *Ecology* 69(6):1762-1767.

Saxena, V.K., R.E. Stogner, A.H. Hendler, T.P. DeFelice, R.J.-Y. Yeh and N.-H. Lin, 1989. Monitoring the chemical climate of the Mt. Mitchell State Park for evaluation of its impact on forest decline. *Tellus* 41B:92-109.

References (continued)

Schemenauer, R.S. and C. Winston, 1988. *The 1986 Chemistry of High Elevation Fog (CHEF) project.* 81st Annual Meeting of the Air Pollution Control Association, 19-24 June, Dallas, 88-129.6:1-16.

Schemenauer, R.S. 1986. Acidic deposition to forests: the 1985 Chemistry of High Elevation Fog (CHEF) project. *Atmosphere-Ocean* 24:303-328.

Schemenauer, R.S., P.H. Schuepp, S. Kermasha and P. Cereceda. 1988. *Measurements of the properties of high elevation fog in Quebec, Canada.* In: Acid Deposition at High Elevation Sites, M.H. Unsworth and D. Fowler (Eds.), Kluwer Academic Publishing, Dordrecht, pp. 359-374.

Shreffler, J.H. and Barnes, Jr., H.M. 1996. Estimation of Trends in Atmospheric Concentrations of Sulfate in the Northeastern United States. *JAWMA* 46:621-630.

Sheih, C.M., Wesely, M.L., and Hicks, B.B. 1979. Estimated Dry Deposition Velocities of Sulfur Over the Eastern United States and Surrounding Waters. Atmos. Environ. 13:1361-1368.

U.S. Environmental Protection Agency (EPA). 1996. *National Air Pollutant Emission Trends, 1990-1995.* EPA-454/R-96-007. OAQPS, RTP, North Carolina 27711.

U.S. Environmental Protection Agency (EPA). 1997. *Examination of CASTNet: Data, Results, Costs, and Implications (Draft).* ORD, Washington, DC 20460.

Vong, R.J., J.T. Sigmon and S.F. Mueller. 1991. Cloud water deposition to Appalachian forests. *Environ. Sci. Technol.* 25:1014-1021.

Wesely, M.L. and Lesht, B.M. 1988. Comparison of RADM Dry Deposition Algorithm with a Site-Specific Method for Inferring Dry Deposition. *Water, Air, and Soil Pollution* 44: 273-293.

Table 2-1. Locations and Operational Dates of CDN Sites

Site No.	Site Name	Latitude (°)	Longitude (°)	Operational Date(s)
Currently Active Sites				
106	PSU, PA	40.73	77.93	01/06/87
107	Parsons, WV	39.09	79.67	01/14/88
108	Prince Edward, VA	37.17	78.31	11/01/87
109	Woodstock, NH	43.94	71.70	12/31/88
110	Connecticut Hill, NY	42.40	76.65	09/14/87
111	Speedwell, TN	36.47	83.83	06/30/89
112	Kane Experimental Forest, PA	41.60	78.77	12/31/88
113	M.K. Goddard State Park, PA	41.43	80.15	01/08/88
114	Deer Creek State Park, OH	39.63	83.26	09/30/88
115	Ann Arbor, MI	42.60	83.92	06/30/88
116	Beltsville, MD	39.03	76.82	12/31/88
117	Laurel Hill State Park, PA	40.00	79.17	12/10/87
119	Cedar Creek State Park, WV	38.88	80.85	11/09/87
120	Horton Station, VA	37.33	80.55	06/03/87
122	Oxford, OH	39.53	84.72	08/18/87
123	Lykens, OH	40.92	83.00	09/30/88
124	Unionville, MI	43.61	83.36	06/30/88
125	Candor, NC	35.26	79.84	09/30/90
126	Cranberry, NC	36.11	82.04	12/31/88
127	Edgar Evins State Park, TN	36.04	85.73	03/22/88
128	Arendtsville, PA	39.92	77.31	06/30/88
130	Bondville, IL	40.05	88.37	02/09/88
131†	Mackville, KY	37.70	85.05	07/31/90
132	Howland, ME	45.22	68.71	12/01/92
133	Salamonie Reservoir, IN	40.82	85.66	06/30/88
134	Perkinstown, WI	45.21	90.60	09/30/88
135†	Ashland, ME	46.61	68.41	12/31/88
136	Crockett, KY	37.92	83.06	08/24/93
137	Coweeta, NC	35.05	83.43	11/03/87
138	Stockton, IL	42.29	90.00	01/01/94
139	Blackwater NWR, MD	38.35	76.11	07/01/95
140	Vincennes, IN	38.70	87.49	08/05/87
142	Beaufort, NC	34.88	76.60	01/08/94
144	Washington's Crossing, NJ	40.31	74.88	12/31/88
145	Lye Brook, VT	43.04	73.06	01/01/94
147	Abington, CT	41.86	72.00	01/15/94
149	Wellston, MI	44.22	85.82	06/30/88
150	Caddo Valley, AR	34.18	93.10	09/30/88
151	Coffeeville, MS	34.00	89.80	12/31/88
152	Sand Mountain, AL	34.29	85.97	12/31/88

Table 2-1. Locations and Operational Dates of CDN Sites (Continued, Page 2 of 3)

Site No.	Site Name	Latitude (°)	Longitude (°)	Operational Date(s)
153	Georgia Station, GA	33.18	84.41	06/30/88
156	Sumatra, FL	30.11	84.99	12/31/88
157	Alhambra, IL	38.87	89.62	06/30/88
161	Gothic, CO	38.96	106.99	06/30/89
165	Pinedale, WY	42.93	109.79	12/31/88
169	Centennial, WY	41.31	106.15	06/30/89
175	Claryville, NY	42.20	74.25	01/15/94
181	Egbert, Ontario	44.23	79.78	11/01/89
MADPro Sites				
300	Whiteface Mountain, NY	44.23	73.59	Seasonal
301	Hunter Mountain, NY	41.10	74.14	Seasonal
302	Whitetop Mountain, VA	36.38	81.36	Seasonal
303	Clingman's Dome, TN	35.34	83.29	Seasonal
NPS Deposition Sites				
401	Big Bend NP, TX	29.31	103.18	07/18/95
402	Sequoia, CA	36.50	118.70	02/25/97
403	Joshua Tree NM, CA	34.07	116.39	02/16/95
404	Yosemite NP, CA	36.43	118.76	09/25/95
405	Mesa Verde NP, CO	37.20	108.49	01/10/95
406	Rocky Mountain NP, CO	40.28	105.55	09/27/94
407	Canyonlands NP, UT	38.46	109.82	01/24/95
408	Yellowstone NP, WY	44.39	110.39	06/26/96
409	Mount Rainier NP, WA	46.76	122.12	08/29/95
410	Lassen Volcanoes NP, CA	40.54	121.57	07/25/95
411	Great Basin NP, NV	39.01	114.22	05/16/95
412	Death Valley NM, CA	36.51	116.85	02/20/95
413	Voyageurs NP, MN	48.41	92.83	06/13/96
414	Pinnacles NM, CA	36.49	121.16	05/16/95
415	Northern Cascades NP, WA	48.54	121.45	02/14/96
418	Big Meadows, VA*	38.52	78.44	06/30/88
467	Chiricahua NM, AZ*	32.01	109.39	07/01/89
468	Glacier NP, MT*	48.51	113.99	01/01/89
474	Grand Canyon NP, AZ*	36.06	112.18	07/01/89
Visibility Sites				
510	Connecticut Hill, NY	42.40	76.65	09/20/93
513	M.K. Goddard, PA	41.43	80.15	09/17/93
518	Shenandoah Mountain Park, VA**	38.52	78.44	10/18/93

Table 2-1. Locations and Operational Dates of CDN Sites (Continued, Page 3 of 3)

Site No.	Site Name	Latitude (°)	Longitude (°)	Operational Date(s)
528	Arendtsville, PA	39.92	77.31	09/16/93
530	Bondville, IL	40.05	88.37	09/24/93
570	Sikes, LA	32.07	92.46	06/10/93
571	Cadiz, KY	36.78	87.85	09/16/93
572	Quaker City, OH	39.94	81.34	07/24/93
573	Livonia, IN	38.58	86.26	12/31/88
Special Study Sites				
180	Scotia Range, PA (wet deposition only)	40.79	77.92	10/01/93
182	Coweeta, NC (ridge)	35.05	83.44	06/27/91-09/30/92
183	Woodstock, NH (ridge)	43.95	71.70	08/11/91-09/30/92
Discontinued Sites				
101	Research Triangle Park, NC	35.91	78.88	01/01/87-01/01/90
102	Oak Ridge, TN	35.96	84.29	01/01/87-01/01/89
103	West Point-A, NY	41.35	74.05	01/01/87-10/01/88
104	West Point-B, NY	41.35	74.05	01/01/87-10/01/93
105	Whiteface Mountain, NY	44.39	73.86	01/01/87-04/01/93
121	Lilley Cornett Woods, KY	37.13	82.99	01/19/88-12/31/93
129	Perryville, KY	37.68	84.97	08/11/87-07/01/90
146	Argonne, IL	41.70	88.00	07/01/87-04/01/93
162	Uinta, UT	40.55	110.32	07/01/89-10/01/93
163	Reynolds Creek, ID	43.21	116.75	06/30/89-10/01/93
164	Saval Ranch, NV	41.29	115.86	06/30/89-10/01/93

*Former EPA CASTNet site.
†Current collocated site.
**Collocated with IMPROVE aerosol sampler.

Source: QST.

Table 2-2. Deployment History of the CDN

Year	No. of Sites*		
	Eastern	Western	Total
1988	16	0	16
1989	41	2	43
1990	41	9	50
1991	41	9	50
1992	41	9	50
1993	42	9	51
1994	46	6	52
1995	45	6	51
1996	13	2	15

*Indicates number of sites in operation as of January 1.

Source: QST.

Table 2-3. Site-Selection Criteria for CDN Sites

Potential Interferant	Minimum Acceptable Distance (km)
SO_2 or NO_x Pt. Source >100 tpy	20
SO_2 or NO_x Pt. Source >1,000 tpy	40
Major Industrial Complex	10
Town, population 1,000 - 10,000	5
Town, population 10,000 - 25,000	10
City, population 15,000-50,000	20
City, population >50,000	40
Major highway, airport, railway	2
Secondary road, heavily traveled	0.5
Secondary road, lightly traveled	0.2
Feedlot operations	0.5
Intensive agricultural activities	0.5
Limited agricultural activities	0.1
Parking lot or large paved area	0.2
Building with fuel combustion	0.2
Sewage treatment plant	1.0
Forced main vent or lift station	0.2
Tree line	0.1
Complex terrain	variable

Note: km = kilometer.

Source: QST.

Table 2-4. CDN Site Listing

Site No.	Site Name	Initial Reporting Date	Latitude	Longitude	Elevation (m)	Primary Land Use	Terrain
104	West Point, NY	01/06/87	41.35	74.05	203	Forested	Complex
105	Whiteface Mountain, NY	01/06/87	44.39	73.86	570	Forested	Complex
106	PSU, PA	01/06/87	40.73	77.95	378	Agricultural	Rolling
107	Parsons, WV	01/14/88	39.09	79.66	510	Forested	Complex
108	Prince Edward, VA	11/01/87	37.17	78.31	146	Forested	Rolling
109	Woodstock, NH	12/31/88	43.94	71.70	258	Forested	Complex
110	Connecticut Hill, NY	09/14/87	42.40	76.65	515	Forested	Rolling
111	Speedwell, TN	07/01/89	36.47	83.83	361	Agricultural	Rolling
112	Kane Experimental Forest, PA	12/31/88	41.60	78.77	622	Forested	Rolling
113	M.K. Goddard, PA	01/08/88	41.43	80.15	384	Forested	Rolling
114	Deer Creek State Park, OH	09/30/88	39.63	83.26	265	Agricultural	Rolling
115	Ann Arbor, MI	06/30/88	42.42	83.90	267	Forested	Flat
116	Beltsville, MD	12/31/88	39.03	76.82	46	Urban-Agric.	Flat
117	Laurel Hill State Park, PA	12/10/87	40.00	79.25	615	Forested	Complex
118	Big Meadows, VA	06/30/88	38.52	78.44	1,073	Forested	Mountaintop
119	Cedar Creek State Park, WV	11/09/87	38.88	80.85	234	Forested	Complex
120	Horton Station, VA	06/03/87	37.33	80.55	920	Forested	Mountaintop
121	Lilley Cornett Woods, KY	01/19/88	37.08	82.99	335	Forested	Complex
122	Oxford, OH	08/18/87	39.53	84.72	284	Agricultural	Rolling
123	Lykens, OH	09/30/88	40.92	83.00	303	Agricultural	Flat
124	Unionville, MI	06/30/88	43.61	83.36	201	Agricultural	Flat
125	Candor, NC	09/30/90	35.26	79.84	198	Forested	Rolling
126	Cranberry, NC	12/31/88	36.11	82.04	1,219	Forested	Mountaintop
127	Edgar Evins State Park, TN	03/22/88	36.04	85.73	302	Forested	Rolling
128	Arendtsville, PA	06/30/88	39.92	77.31	269	Agricultural	Rolling
129	Perryville, KY	06/88	37.68	84.97	279	Agricultural	Rolling
130	Bondville, IL	02/09/88	40.05	88.37	212	Agricultural	Flat
131	Mackville, KY	07/31/90	37.70	85.05	353	Agricultural	Rolling
132	Howland, ME	12/01/92	45.22	68.71	69	Forested	Rolling
133	Salamonie, IN	06/30/88	40.82	85.66	249	Agricultural	Flat
134	Perkinstown, WI	09/30/88	45.21	90.60	472	Agricultural	Rolling
135	Ashland, ME	12/31/88	46.61	68.41	235	Agricultural	Flat
136	Crockett, KY	08/24/93	37.92	83.06	455	Agricultural	Flat and Open
137	Coweeta, NC	11/03/87	35.06	83.43	686	Forested	Complex
138	Stockton, IL	01/01/94	42.29	90.00	274	Agricultural	Rolling and Open
139	Blackwater NWR, MD	07/01/95	38.35	76.11	~sea level	Wetland	Coastal Plain
140	Vincennes, IN	08/05/87	38.74	87.49	134	Agricultural	Rolling
142	Beaufort, NC	01/08/94	34.88	76.60	~sea level	Agricultural	Flat and Open
144	Washington's Crossing, NJ	12/31/88	40.30	74.87	58	Agric.-Urban	Rolling
145	Lye Brook, VT	01/01/94	43.04	73.06	730	Forested	Complex
146	Argonne National Laboratory, IL	07/01/87	41.70	87.99	229	Urban-Agric.	Flat
147	Abington, CT	01/15/94	41.86	72.00	209	Urban-Agric.	Complex
149	Wellston, MI	06/30/88	44.22	85.82	295	Forested	Flat
150	Caddo Valley, AR	09/30/88	34.18	93.10	71	Forested	Rolling
151	Coffeeville, MS	12/31/88	34.00	89.80	134	Forested	Rolling
152	Sand Mountain, AL	12/31/88	34.29	85.97	352	Agricultural	Rolling

Table 2-4. Continued, Page 2 of 2

Site No.	Site Name	Initial Reporting Date	Latitude	Longitude	Elevation (m)	Primary Land Use	Terrain
153	Georgia Station, GA	06/30/88	33.18	84.41	270	Agricultural	Rolling
156	Sumatra, FL	12/31/88	30.11	84.99	14	Forested	Flat
157	Alhambra, IL	06/30/88	38.87	89.62	164	Agricultural	Flat
161	Gothic, CO	07/01/89	38.96	106.99	2,926	Range	Complex
162	Uinta, UT	07/01/89	40.55	110.32	2,500	Range	Complex
163	Reynolds Creek, ID	07/01/89	43.21	116.75	1,198	Range	Rolling
164	Saval Ranch, NV	07/01/89	41.29	115.86	1,873	Range	Rolling
165	Pinedale, WY	12/31/88	42.93	109.79	2,388	Range	Rolling
167	Chiricahua, AZ	07/01/89	32.01	109.39	1,570	Range	Complex
168	Glacier National Park, MT	12/31/88	48.51	114.00	963	Forested	Complex
169	Centennial, WY	07/01/89	41.31	106.15	2,579	Range	Complex
174	Grand Canyon, AZ	07/01/89	36.06	112.18	2,073	Forested	Complex
175	Claryville, NY	01/15/94	42.20	74.25	825	Forested	Complex
181	Egbert, Ontario	11/01/89	44.23	79.76	251	Agricultural	Rolling

Source: QST.

Table 2-5. Precision and Accuracy Objectives of CDN Field Measurements

Measurement Parameter	Method	Objectives*	
		Precision	Accuracy
Windspeed	Anemometer	±0.5 m/sec	the greater of ±0.2 m/sec or ±5%
Wind Direction	Wind Vane	±5°	±5°
Sigma Theta	Wind Vane	±10%	Undefined
Relative Humidity	Hygrometer	±10% (of full scale)	±10% (of full scale)
Solar Radiation	Pyranometer	±10% (of reading taken at local noon)	±10%
Precipitation	Rain Gauge	±10% (of reading)	±0.05 inch†
Ambient Temperature	Platinum RTD	±0.5°C	±0.25°C
Delta Temperature	Platinum RTD	±0.25°C	±0.25°C
O_3	UV Absorbance	±10% (of reading)	±10%
Filter Pack Flow	Mass Flow Controller	±0.15 L/min	±10%
Surface Wetness	Conductivity Bridge	Undefined	Undefined

Note: m/sec = meters per second.
RTD = resistance-temperature device.

*Precision criteria apply to collocated instruments, and accuracy criteria apply to calibration of instruments.
†For target value of 0.50 inch.

Source: QST.

Table 2-6. Chemical Analysis of Samples Plus QC Solutions (Periods of Record)

Sample Medium	Analyte(s)	Period of Record
Teflon® filter extract	SO_4^{2-}, NO_3^-	1/87 - present
Teflon® filter extract	NH_4^+	6/88 - present
Teflon® filter extract	Na^+, K^+, Ca^{2+}, Mg^{2+}	6/88 - 9/89
Nylon filter extract	SO_4^{2-}, NO_3^-	1/87 - present
Whatman filter extract	SO_4^{2-}, NO_3^-	1/87 - present
Precipitation samples	pH, conductivity, acidity, Cl^-, NO_2^-, NO_3^-, SO_4^{2-}, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}	1/89 - present
Fine particulate filters	Tare/final mass	1/89 - 12/89
Coarse particulate filters	Tare/final mass	1/89 - 12/89

Note: Precipitation and particulate filters collected at selected sites, other analyses performed for all CDN sites.

Source: QST.

Table 2-7. Schedule of Routine QC Checks, Calibrations, and Audits Performed at CDN Sites

Observable	Measurement Device	Performance Test Frequency	Performance Standard	Calibration Frequency	Calibration Standard	Audit Frequency	Audit Standard	Primary
Windspeed (Vector and Scalar)	Anemometer	Weekly	Visually check anemometer speed, compare with recorded value	Quarterly	Constant-rpm motor, frequency measurement	Semiannual or annual*	Constant-rpm motor	Yearly factory recertification
Wind Direction/ Sigma Theta	Vane	Weekly	Visually check wind vane direction, compare with recorded value	Quarterly	Alignment with true north, field transit	Semiannual or annual*	Brunton compass	Second-order theodolite
Air Temperature/ Delta Temperature	Resistance thermometer	Weekly	Electronic check	Quarterly	NIST-traceable platinum RTD	Semiannual or annual*	Assman psychrometer	NIST-traceable thermometer
Humidity	Strain gauge	Weekly	Electronic check	Quarterly	Collocated NIST-traceable sensor	Semiannual or annual*	Assman psychrometer	NIST-traceable thermometer
Solar Radiation	Pyranometer	Weekly	Compare recorded value with observed solar intensity; zero check	Quarterly	Eppley radiometer	Semiannual or annual*	Eppley radiometer	Yearly factory calibration of transfer standard
Precipitation Measurement	Tipping-bucket rain gauge	Weekly	Manual tip check	Quarterly	Addition of known volumes	Semiannual or annual*	Addition of known volumes	NIST-traceable volumes
Precipitation Collection	Wet/dry collector	Weekly	Wet sensor, measure time lid remains open	Quarterly	Wet sensor, measure time lid remains open	Semiannual or annual*	Wet sensor, record time lid remains open	None

Table 2-7. Continued, Page 2 of 2

Observable	Measurement Device	Performance Test Frequency	Performance Standard	Calibration Frequency	Calibration Standard	Audit Frequency	Audit Standard	Primary
O_3	UV absorbance	Every third day	Zero, span (400 ppb), and precision (60 ppb)	Quarterly	NIST-traceable O_3 generator	Semiannual or annual*	Thermo Environmental 49-103P	Photometer at EPA, RTP, NC
Filter Pack Flow	Filter pack mass flow controller	Weekly	Check recorded flow value, compare with set value, leak check	Quarterly	Mass flow meter	Semiannual or annual*	Mass flow meter	NIST-traceable bubble meter
Surface Wetness	Conductivity bridge	Weekly	Check output when wetted	Quarterly	Check output when wetted	Semiannual or annual*	Check output when wetted	None

Note: ppb = parts per billion.
rpm = revolutions per minute.

*Semiannual audit performed from January 1987 through October 1989; annual audits performed from November 1989 to present.

Source: QST.

Table 2-8. Schedule of Routine QC Checks, Calibrations, and Audits Performed at the CDN Laboratory (QST)

Observable	Measurement Device	Performance Test Frequency	Performance Standard	Calibration Frequency	Calibration Standard	Audit Frequency	Audit Standard	Primary
Total Acidity	Titration	One per batch or daily	Blanks, standards	Daily	NIST-traceable pH 4 and pH 7 potassium hydrogen phthalate (as primary standard)	Semiannual or annual*	Reference standards	EPA/NIST reference standards
Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}	Atomic absorption	One per batch or daily	Blanks, standards, replicates, independent reference standards	Daily	Reagent-grade chemicals	Semiannual or annual*	Reference standards	EPA/NIST reference standards
NH_4^+	Automated wet chemical	One per batch or daily	Blanks, standards, replicates, independent reference standards	Daily	Reagent-grade chemicals	Semiannual or annual*	Reference standards	EPA/NIST reference standards
NO_2^-, NO_3^-, Cl^-, SO_4^{2-}	Suppressed ion chromatography	One per batch or daily	Blanks, standards, replicates, independent reference standards	Daily	Reagent-grade chemicals	Semiannual or annual*	Reference standards	EPA/NIST reference standards
Fine/Coarse Aerosol Mass	Gravimetric (micro-balance)	One per batch or daily	Class S weight	Daily	Class S weight	Semiannual or annual*	Class S weight	NIST reference weight

*Semiannual audits performed from January 1987 through October 1989; annual audits performed November 1989 to present.

Source: QST.

Table 2-9. Precision and Accuracy Objectives for CDN Laboratory Data

Analyte	Medium	Method	Objectives* Precision (RPD)	Objectives* Accuracy (%)
pH*	W	Electrometric	12	88 - 112
Conductivity	W	Electrometric	10	90 - 110
Acidity	W	Titrimetric	15	85 - 115
NH_4^+	W/F	Automated colorimetry	10	90 - 110
Na^+	W/F	ICP-AE	10	90 - 110
K^+	W/F	Flame atomic emission	10	90 - 110
Mg^{2+}	W/F	ICP-AE	10	90 - 110
Ca^{2+}	W/F	ICP-AE	10	90 - 110
Cl^-	W	IC	5	95 - 105
NO_2^-	W	IC	5	95 - 105
NO_3^-	W/F	IC	5	95 - 105
SO_4^{2-}	W/F	IC	5	95 - 105

Note: W = wet deposition samples.
F = filter pack samples.
IC = ion chromatography.
ICP-AE = inductively coupled plasma - atomic emission.
RPD = relative percent difference.

*Precision and accuracy criteria represent ± 0.05 pH unit.

Source: QST.

Table 2-10. Summary Statistics for Collocated Continuous Data for All Years, 1987 through 1995

Site		Average Value Over the Project									
		Delta Temperature (°C)	Ozone (ppb)	Rainfall (mm/hr)	Relative Humidity (%)	Windspeed (m/sec)	Sigma Theta (°)	Solar Radiation (W/m²)	Temperature (°C)	Wind Direction (°)	Wetness (Fraction of Time)
107	Mean X	0.04	34.64	1.25	73.92	2.22	29.79	161.17	12.53	81.85	0.85
	Mean Y	0.02	35.30	1.24	75.67	2.39	30.24	171.95	13.02	82.38	0.82
	N	8,336.00	8,620.00	990.00	8,270.00	8,643.00	8,249.00	6,776.00	8,334.00	8,249.00	2,702.00
	RPD	87.72	-1.88	1.04	-2.34	-7.28	-1.50	-6.47	-3.81	-0.65	3.56
	Median AD	0.05	1.00	0.20	2.00	0.20	1.00	10.00	0.20	3.00	0.00
	Median APD	N/A	2.02	4.26	2.41	11.11	6.45	4.20	N/A	3.57	0.00
114	Mean X	0.14	30.98	1.39	76.47	2.78	16.52	167.56	12.09	93.81	0.67
	Mean Y	0.16	32.69	1.37	76.04	2.85	16.16	162.75	12.02	94.14	0.81
	N	16,640.00	16,862.00	911.00	15,807.00	15,878.00	16,392.00	15,638.00	15,805.00	16,455.00	3,667.00
	RPD	-11.06	-5.38	1.70	0.58	-2.60	2.22	2.91	0.59	-0.36	-18.86
	Median AD	0.07	2.00	0.20	3.00	0.10	0.00	8.00	0.10	1.00	0.00
	Median APD	N/A	5.88	8.33	4.40	2.06	0.00	4.35	N/A	1.45	0.00
128	Mean X	0.16	35.23	1.53	64.42	3.36	17.47	154.29	10.74	85.53	0.82
	Mean Y	0.16	34.93	1.50	66.59	3.33	18.46	153.47	11.69	85.93	0.81
	N	40,596.00	40,505.00	2,408.00	39,294.00	40,499.00	40,130.00	40,299.00	40,738.00	40,132.00	8,173.00
	RPD	-1.29	0.83	2.29	-3.31	0.97	-5.50	0.53	-8.47	-0.47	1.65
	Median AD	0.06	1.00	0.20	4.00	0.10	1.00	4.00	0.10	2.00	0.00
	Median APD	N/A	2.20	6.06	6.80	5.22	8.70	2.08	N/A	2.15	0.00
131	Mean X	0.13	38.12	1.69	72.33	2.84	15.14	166.72	13.39	103.68	0.76
	Mean Y	0.12	38.66	1.66	72.68	2.88	15.67	167.70	13.42	103.90	0.77
	N	21,810.00	23,124.00	1,772.00	22,436.00	22,998.00	22,967.00	22,668.00	21,978.00	22,995.00	8,463.00
	RPD	9.05	-1.41	1.68	-0.48	-1.18	-3.42	-0.59	-0.24	-0.21	-1.06
	Median AD	0.04	1.00	0.20	3.00	0.10	0.00	5.00	0.10	2.00	0.00
	Median APD	N/A	1.94	3.51	3.57	3.77	0.00	3.37	N/A	1.76	0.00
153	Mean X	0.23	43.16	2.20	74.47	2.03	21.14	197.42	19.15	96.07	0.81
	Mean Y	0.26	43.60	2.24	76.17	2.03	20.02	206.24	18.92	96.73	0.64
	N	5,645.00	6,763.00	375.00	7,086.00	7,046.00	7,046.00	4,972.00	7,039.00	7,046.00	2,283.00
	RPD	-11.11	-1.02	-1.85	-2.25	0.29	5.44	-4.37	1.24	-0.68	23.93
	Median AD	0.03	1.00	0.20	2.00	0.10	1.00	12.00	0.10	3.00	0.00
	Median APD	N/A	1.21	4.44	2.56	2.74	5.71	4.70	N/A	3.24	0.00

Table 2-10. Continued, Page 2 of 2

Site		Average Value Over the Project: Delta Temperature (°C)	Ozone (ppb)	Rainfall (mm/hr)	Relative Humidity (%)	Windspeed (m/sec)	Sigma Theta (°)	Solar Radiation (W/m²)	Temperature (°C)	Wind Direction (°)	Wetness (Fraction of Time)
156	Mean X	0.13	30.61	3.13	80.18	1.74	23.92	164.75	18.39	78.52	0.80
	Mean Y	0.16	29.64	3.20	80.79	1.68	24.06	163.96	18.48	78.53	0.78
	N	20,788.00	20,327.00	1,155.00	20,575.00	20,234.00	20,460.00	19,994.00	20,807.00	20,536.00	7,363.00
	RPD	-20.67	3.20	-2.28	-0.75	3.69	-0.56	0.48	-0.47	-0.01	1.67
	Median AD	0.08	1.00	0.20	2.00	0.10	1.00	6.00	0.10	1.00	0.00
	Median APD	N/A	4.26	7.59	2.38	5.13	2.53	2.36	N/A	2.25	0.00
157	Mean X	0.34	37.49	1.83	70.35	3.76	9.93	207.86	15.13	100.09	0.84
	Mean Y	0.29	37.64	1.67	74.78	3.95	10.83	203.61	15.30	103.05	0.73
	N	8,685.00	8,528.00	500.00	8,684.00	8,414.00	8,614.00	8,714.00	8,684.00	8,414.00	1,792.00
	RPD	16.16	-0.39	8.75	-6.10	-4.87	-8.66	2.06	-1.11	-2.92	14.34
	Median AD	0.05	1.00	0.20	6.00	0.20	1.00	10.00	0.30	4.00	0.00
	Median APD	N/A	1.60	9.20	8.00	4.44	18.18	3.81	N/A	4.08	0.00
163	Mean X	0.48	37.47	0.75	49.32	2.99	27.36	175.09	8.87	101.70	0.64
	Mean Y	0.37	37.15	0.76	47.82	2.92	27.65	176.57	9.13	101.72	0.51
	N	19,532.00	18,980.00	461.00	19,546.00	19,282.00	19,298.00	19,637.00	19,534.00	19,336.00	3,886.00
	RPD	27.85	0.87	-1.84	3.10	2.41	-1.04	-0.84	-2.94	-0.02	22.64
	Median AD	0.07	1.00	0.00	3.00	0.10	1.00	6.00	0.10	2.00	0.21
	Median APD	N/A	2.15	0.00	6.67	1.98	3.51	2.52	N/A	1.94	150.88
167	Mean X	0.17	41.67	1.26	46.87	2.84	26.07	224.68	14.59	94.81	0.72
	Mean Y	0.16	41.11	1.36	46.54	2.89	25.85	223.90	14.86	94.44	0.73
	N	1,424.00	22,378.00	613.00	23,736.00	23,723.00	23,262.00	23,813.00	22,804.00	23,256.00	3,143.00
	RPD	3.68	1.35	-7.40	0.72	-1.53	0.84	0.35	-1.86	0.39	-1.50
	Median AD	0.07	1.00	0.20	3.00	0.10	1.00	8.00	0.10	2.00	0.00
	Median APD	N/A	2.11	11.43	6.15	3.33	3.39	2.72	N/A	1.94	0.00

Note: median AD = median absolute difference.
median APD = median absolute percent difference.
mm/hr = millimeters per hour.
N/A = not applicable.
W/m² = watts per square meter.
mean X and Y = mean value for primary and collocated sensors, respectively.
RPD = relative percent difference.

Source: QST.

Table 2-11. Operational Dates for Collocated Filter Pack Monitoring Sites

Site	Beginning Date	Ending Date
107/207	04/01/89	09/30/90
114/214	10/01/90	09/30/92
128/228	10/01/90	06/30/95
131/231	01/01/93	09/30/95
153/253	04/01/89	09/30/90
156/256	10/01/90	03/31/93
157/257	04/01/89	09/30/90
163/263	10/01/90	12/31/92
167/267	01/01/90	09/30/92

Source: QST.

Table 2-12. Network Precision Values for Continuous Data as Estimated from Collocated Sampling Results, Presented as Absolute RPDs, Averaged Over All Years, All Sites

	Average Value Over the Project (Absolute RPD)									
Site	Delta Temperature	Ozone	Rainfall	Relative Humidity	Windspeed	Sigma Theta	Solar Radiation	Temperature	Wind Direction	Wetness
All Sites	20.95	1.81	3.20	2.18	2.76	3.24	2.07	2.30	0.63	9.91

Note: RPD = relative percent difference.

Source: QST.

Table 2-13. Summary Statistics for Collocated Continuous Data for 1994

Site		Delta Temperature (°C)	Ozone (ppb)	Rainfall (mm/hr)	Relative Humidity (%)	Windspeed (m/sec)	Sigma Theta (°)	Radiation (W/m^2)	Temperature (°C)	Wind Direction (°)	Wetness (Fraction of Time)
		Average Value Over the Project									
128	Mean X	0.24	37.32	1.96	63.22	3.43	17.87	162.14	11.17	84.05	0.81
	Mean Y	0.22	37.84	1.85	68.35	3.26	18.98	162.74	14.90	86.17	0.83
	N	8,578.00	8,549.00	367.00	8,579.00	8,520.00	8,508.00	8,382.00	8,578.00	8508.00	1,892.00
	RPD	10.25	-1.38	5.90	-7.80	4.98	-5.99	-0.37	-28.67	-2.50	-3.00
	Median AD	0.03	1.00	0.20	6.00	0.20	1.00	7.00	0.20	2.00	0.00
	Median APD	NA	1.98	8.33	9.52	6.06	8.00	3.17	NA	3.24	0.00
131	Mean X	0.15	37.83	1.73	70.77	2.93	14.26	167.34	13.10	105.25	0.75
	Mean Y	0.10	38.54	1.73	73.15	2.96	15.32	161.09	12.98	106.04	0.76
	N	7,564.00	8,367.00	712.00	8,215.00	8,423.00	8,392.00	8,489.00	7,606.00	8411.00	3,086.00
	RPD	35.66	-1.86	0.22	-3.31	-0.96	-7.19	3.81	0.90	-0.75	-0.89
	Median AD	0.07	1.00	0.20	3.00	0.10	0.00	8.00	0.10	5.00	0.00
	Median APD	NA	2.15	5.41	3.92	3.51	0.00	5.22	NA	3.98	0.00

Note: median AD = median absolute difference.
median APD = median absolute percent difference.
mm/hr = millimeters per hour.
NA = not applicable.
W/m^2 = watts per square meter.
mean X and Y = mean value for primary and collocated sensors, respectively.
RPD = relataive percent difference.

Source: QST.

Table 2-14. Summary Results of External QA Performance Audits of Monitoring Sites for 1994

Site No.	Audit Date	T	Delta T	RH	SR	Rain-fall	Wind-speed	Wind Direc-tion	O_3	Filter Pack Flow	Wet-ness
107	05/03/94	P	P	W	P	P	P	P	P	P	P
108	05/08/94	P	P	P	P	P	P	P	P	P	P
109	06/25/94	P	P	P	P	P	P	P	P	P	P
110	06/20/94	P	P	W	P	P	P	P	P	P	P
111	12/01/94	P	P	F	P	P	F	P	P	P	P
114	04/22/94	P	P	P	P	P	P	P	P	P	P
115	04/25/94	P	P	P	P	P	P	P	P	P	P
118	05/09/94	P	P	W	P	P	P	P	P	P	P
119	05/05/94	P	P	P	P	P	P	P	P	P	P
120	05/06/94	P	P	P	P	P	P	P	P	P	P
122	04/21/94	P	P	P	P	F	P	P	P	P	P
123	04/23/94	P	P	P	P	P	P	P	P	P	P
124	04/26/94	P	P	W	P	P	P	P	P	P	P
125	05/07/94	P	P	P	P	P	P	P	P	P	P
126	12/06/94	P	P	P	P	P	P	P	P	P	P
127	12/03/94	P	P	P	P	P	P	P	P	P	P
130	11/14/94	W	P	P	P	P	P	P	P	P	P
131	11/30/94	P	P	P	P	P	P	P	P	P	P
132	06/28/94	P	P	W	P	P	P	P	P	P	P
133	11/16/94	P	P	P	P	P	P	P	P	P	P
134	11/10/94	P	P	P	P	P	P	P	P	W	P
135	06/26/94	P	P	P	P	P	P	P	P	P	P
137	12/05/94	P	P	P	P	P	P	P	P	P	P
138	11/12/94	P	P	P	P	P	P	P	P	P	P
140	11/17/94	P	P	P	F	P	P	P	P	P	P
142	05/11/94	P	P	W	P	P	P	P	P	P	P
144	06/17/94	P	P	W	P	P	P	P	P	P	P
145	06/23/94	P	P	P	P	P	P	P	NA	P	P
149	04/27/94	P	P	P	P	P	P	P	P	P	P
150	03/28/94	P	P	P	P	P	P	P	P	P	P
151	03/26/94	P	P	P	P	P	P	P	P	P	P
152	03/24/94	P	P	W	P	P	P	P	P	P	P
153	03/23/94	P	P	P	P	P	P	P	P	P	P
156	04/02/94	P	P	P	P	P	P	P	P	P	P
157	11/19/94	P	P	W	P	F	P	P	P	P	P
161	10/12/94	P	P	P	P	P	P	P	P	P	P
165	10/09/94	P	F	P	P	P	P	P	P	P	P
167	10/16/94	P	P	P	P	P	P	P	P	P	P
168	10/06/94	P	P	P	P	P	P	P	P	P	P
169	10/10/94	P	P	P	F	P	P	P	P	P	P
174	10/14/94	P	P	P	P	P	P	P	P	P	P

Table 2-14. Continued, Page 2 of 2

Site No.	Audit Date	T	Delta T	RH	SR	Rain-fall	Wind-speed	Wind Direc-tion	O_3	Filter Pack Flow	Wet-ness
175	06/30/94	F	F	P	P	P	P	P	NA	P	P
231	11/30/94	F	P	P	P	P	P	P	P	P	P
Failures		**2**	**2**	**1**	**2**	**2**	**1**	**0**	**2**	**0**	**0**
Total Failures		**12**									
Warnings		**1**	**0**	**9**	**0**	**0**	**0**	**0**	**0**	**1**	**0**
Total Warnings		**11**									

Note: F = fail.
NA = not applicable.
P = pass.
RH = relative humidity.
SR = solar radiation.
T = temperature.
W = warning.

Source: QST.

Table 2-15. Summary Statistics of External QA Performance Audits of Monitoring Sites for 1994

	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	Total
Number of Sites Audited	5	20	0	18	**43**
Number of Sensors Audited	50	200	0	180	**430**
Number of Sensor Failures	0	5	0	7	**12**
Number of Sensor Warnings	1	7	0	3	**11**
Percent Failure	0.0	2.5	0	3.9	**2.7**
Percent Warning	2.0	3.5	0	1.7	**2.6**

Source: QST.

Table 2-16. Summary Statistics for Collocated Filter Pack Data for All Years, 1987 through 1995

Site		SO_4^{2-}	NO_3^-	NH_4^+	HNO_3	SO_2	Total NO_3^-
107	Mean X*	7.58	0.65	1.83	2.09	12.34	2.68
	Mean Y*	7.65	0.58	1.84	1.93	11.94	2.47
	N	77.00	77.00	77.00	79.00	79.0	77.00
	RPD	-0.90	10.59	-0.83	7.90	3.26	8.38
	Median AD	0.11	0.07	0.04	0.15	0.46	0.22
	Median APD	2.03	16.46	2.45	6.50	4.46	8.62
114	Mean X*	6.34	1.64	2.41	2.91	12.71	4.53
	Mean Y*	6.14	1.59	2.35	2.91	12.54	4.48
	N	96.00	96.00	96.00	72.00	72.00	72.00
	RPD	3.19	3.03	2.72	-0.13	1.38	1.15
	Median AD	0.23	0.10	0.08	0.12	0.45	0.19
	Median APD	4.67	7.80	3.93	4.68	4.86	4.91
128	Mean X*	5.95	1.54	2.26	3.47	14.43	4.95
	Mean Y*	6.02	1.59	2.26	3.46	14.44	5.00
	N	231.00	231.00	230.00	231.00	231.00	231.00
	RPD	1.03	-3.42	-0.04	0.24	-0.03	-0.91
	Median AD	0.14	0.09	0.05	0.30	0.49	0.29
	Median APD	2.63	8.18	2.63	9.58	4.09	6.08
131	Mean X*	6.68	1.01	2.24	3.03	9.81	4.01
	Mean Y*	6.46	0.99	2.15	2.93	9.48	3.88
	N	129.00	129.00	128.00	131.00	131.00	129.00
	RPD	3.26	2.72	4.02	3.44	3.37	3.26
	Median AD	0.30	0.05	0.11	0.14	0.41	0.18
	Median APD	5.77	6.99	5.60	5.77	4.92	5.20
153	Mean X*	6.56	0.43	1.87	2.25	7.83	2.66
	Mean Y*	6.56	0.40	1.82	2.29	7.90	2.67
	N	68.00	68.00	67.00	70.00	70.00	68.00
	RPD	0.09	7.61	2.54	-1.86	-0.81	-0.54
	Median AD	0.19	0.04	0.07	0.11	0.25	0.13
	Median APD	4.12	14.95	5.11	6.21	4.30	6.30
156	Mean X*	3.90	0.48	0.83	1.01	2.23	1.48
	Mean Y*	3.79	0.48	0.81	1.03	2.31	1.50
	N	114.00	114.00	111.00	88.00	89.00	87.00
	RPD	2.76	-1.22	2.03	-2.66	-3.86	-1.79
	Median AD	0.13	0.03	0.03	0.06	0.14	0.08
	Median APD	3.50	9.36	3.85	6.40	7.12	5.88
157	Mean X*	6.94	2.56	2.83	2.48	12.65	4.99
	Mean Y*	6.87	2.50	2.77	2.40	12.28	4.85
	N	79.00	79.00	79.00	81.00	81.00	79.00
	RPD	0.98	2.34	1.96	3.36	2.95	2.94
	Median AD	0.10	0.09	0.04	0.11	0.32	0.15
	Median APD	1.30	4.80	1.94	4.49	2.67	2.94

Table 2-16. Continued, Page 2 of 2

Site		SO_4^{2-}	NO_3^-	NH_4^+	HNO_3	SO_2	Total NO_3^-
163	Mean X*	0.70	0.59	0.37	0.37	0.29	0.95
	Mean Y*	0.69	0.59	0.37	0.36	0.29	0.95
	N	114.00	114.00	113.00	113.00	113.00	113.00
	RPD	1.10	-0.46	-0.99	1.30	0.03	0.15
	Median AD	0.02	0.02	0.01	0.01	0.02	0.02
	Median APD	2.60	5.22	2.88	4.58	7.10	3.39
167	Mean X*	1.43	0.29	0.47	0.64	1.98	0.93
	Mean Y*	1.44	0.29	0.47	0.64	2.01	0.93
	N	172.00	172.00	172.00	146.00	146.00	146.00
	RPD	-0.77	-1.46	-0.78	0.47	-1.49	-0.15
	Median AD	0.02	0.02	0.01	0.02	0.05	0.03
	Median APD	1.63	6.33	2.01	3.32	3.37	2.93

Note: median AD = median absolute difference.
median APD = median absolute percent difference.
mean X and Y = mean value for primary and collocated sensors, respectively.
RPD = relative percent difference.

*Values in $\mu g/m^3$.

Source: QST.

Table 2-17. Network Precision Values for Filter Pack Data as Estimated from Collocated Sampling Results, Presented as Absolute RPDs, Averaged Over All Years, All Sites

SO_4^{2-}	NO_3^-	NH_4^+	HNO_3	SO_2	Total NO_3^-
1.56	3.65	1.77	2.37	1.91	2.14

Source: QST.

Table 2-18. Summary Statistics for Collocated Filter Pack Data for 1994

Site		SO_4^{2-}	NO_3^-	NH_4^+	HNO_3	SO_2	Total NO_3^-
128	Mean X*	5.88	1.22	2.11	4.18	15.61	5.34
	Mean Y*	5.82	1.29	2.10	3.69	14.94	4.91
	N	50.00	50.00	50.00	50.00	50.00	50.00
	RPD	1.16	-5.04	0.40	12.60	4.40	8.28
	Median AD	0.16	0.15	0.07	0.46	0.50	0.40
	Median APD	2.72	17.04	3.66	12.83	3.56	8.73
131	Mean X*	6.59	0.99	2.14	2.94	9.89	3.90
	Mean Y*	6.43	0.95	2.05	2.86	9.59	3.78
	N	43.00	43.00	43.00	44.00	44.00	43.00
	RPD	2.55	3.83	4.16	2.86	3.05	3.06
	Median AD	0.29	0.04	0.09	0.14	0.36	0.18
	Median APD	4.65	6.19	4.51	5.56	3.93	4.83

Note: median AD = median absolute difference.
median APD = median absolute percent difference.
mean X and Y = mean value for primary and collocated sensors, respectively.
RPD = relative percent difference.

*Values in $\mu g/m^3$.

Source: QST.

Table 2-19. Laboratory Precision and Accuracy Results for Concentration Data, 1994 Annual Averages

Filter Type	Parameter	Reference Sample Recovery (%)		Continuing Verification Samples (%)		Blind Replicate Percent Difference*		In-Run Replicate Percent Difference	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Teflon®	SO_4^{2-}	100.23	1.49	98.46	1.04	1.21	2.07	0.58	0.98
	NO_3^-	99.1	1.18	99.21	0.78	2.59	4.17	1.09	1.6
Nylon	SO_4^{2-}	100.4	1.89	99.10	1.10	3.66	5.26	1.80	2.92
	NO_3^-	98.61	0.99	98.52	0.91	1.38	1.86	0.85	1.04
Whatman	SO_4^{2-}	100.23	1.23	99.92	1.13	2.84	6.34	2.15	3.76
	NO_3^-	98.47	0.89	98.98	1.02	6.25	7.48	3.23	3.70

*Field blanks deleted from statistics.

Source: QST.

Table 2-20. Laboratory Precision and Accuracy Results for Concentration Data, 1987 to 1995 Grand Averages

Filter Type	Parameter	Reference Sample Recovery (%)		Continuing Verification Samples (%)		Blind Replicate Percent Difference*		In-Run Replicate Percent Difference	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Teflon®	SO_4^{2-}	100.36	1.22	99.1	1.33	1.33	2.93	0.62	1.03
	NO_3^-	99.24	1.17	99.62	1.16	5.87	9.81	1.41	2.95
Nylon	SO_4^{2-}	100.68	1.53	99.44	1.86	3.78	6.21	1.94	4.31
	NO_3^-	99.25	1.32	99.36	1.49	1.64	4.51	0.96	1.29
Whatman	SO_4^{2-}	100.48	1.26	99.68	1.69	3.04	7.76	2.22	4.01
	NO_3^-	99.23	1.15	99.23	1.58	8.24	9.46	3.73	4.98

*Field blanks deleted from statistics.

Source: QST.

Table 2-21. Summary Statistics for Collocated Wet Deposition Data for All Years, 1989 to 1995

Parameter	Mean X*	Mean Y*	N	RPD	Median AD	Median APD
Site 128						
Ca^{2+}	13.50	13.61	107	-0.79	1.70	25.09
H^+	70.13	75.80	100	-7.77	4.50	9.00
Mg^{2+}	3.53	3.86	107	-8.95	0.33	16.83
Na^+	6.39	7.30	107	-13.41	0.41	13.30
NH_4^+	33.68	40.48	107	-18.32	2.22	11.31
NO_3^-	46.66	49.60	107	-6.11	2.27	7.77
Rain	1.80	1.76	124	1.87	0.08	6.40
SO_4^{2-}	87.17	87.08	107	0.11	4.38	8.21
Site 157						
Ca^+	15.69	16.68	85	-6.16	1.80	19.14
H^+	37.80	36.59	80	3.24	3.75	13.75
Mg^{2+}	3.52	3.72	85	-5.47	0.63	20.11
Na^+	3.90	3.99	85	-2.23	0.48	19.20
NH_4^+	31.50	28.55	85	9.82	2.78	11.20
NO_3^-	29.02	30.57	85	-5.20	1.56	9.22
Rain	1.89	1.97	110	-4.06	0.10	7.73
SO_4^{2-}	56.33	56.05	85	0.50	3.96	7.86

*Values in $\mu g/m^3$.

Source: QST.

Table 2-22. Operational Dates of Collocated Wet Deposition Monitoring Sites

Site	Beginning Date	Ending Date
157/257	8/10/93	9/19/95
128/228	9/18/90	1/26/93

Source: QST.

Table 2-23. Network Precision Values for Wet Deposition Data as Estimated from Collocated Sampling Results, Presented as Absolute RPDs, Averaged Over All Years, All Sites

Parameter	Absolute RPD
Ca^{2+}	3.48
H^{+}	5.50
Mg^{2+}	7.21
Na^{+}	7.82
NH_4^{+}	14.07
NO_3^{-}	5.66
Rain	2.96
SO_4^{2-}	0.30

Note: RPD = relative percent difference.

Source: QST.

Table 2-24. Summary Statistics for Collocated Wet Deposition Data for 1994

Parameter	Mean X*	Mean Y*	N	RPD	Median AD	Median APD
Ca^{2+}	16.72	20.85	44	-21.95	1.35	17.98
H^{+}	41.17	38.54	41	6.53	3.30	9.32
Mg^{2+}	3.82	4.60	44	-18.74	0.54	14.72
Na^{2+}	3.66	4.16	44	-12.73	0.55	19.15
NH_4^{+}	31.42	31.72	44	-0.95	2.44	9.92
NO_3^{-}	30.91	33.61	44	-8.36	1.21	6.01
Rain	1.49	1.60	51	-6.75	0.10	12.50
SO_4^{2-}	61.08	63.82	44	-4.39	2.08	5.80

Note: median AD = median absolute difference.
median APD = median absolute percent difference.
mean X and Y = mean value for primary and collocated sensors, respectively.
RPD = relative percent difference.

*Values in $\mu g/m^3$, except rain which is millimeters.

Source: QST.

Table 2-25. Laboratory Precision and Accuracy Results for Precipitation Concentration Data, 1994 Annual Averages

Parameter	Reference Sample Recovery (%)		Continuing Verification Samples (%)		Replicate Percent Difference		Unknown Reference Check Samples (%)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
pH (as H^+)	104.19	4.41	95.17	4.95	5.15	5.68	96.28	8.78
Conductivity	103.09	4.38	103.08	4.24	1.41	1.82	106.07	5.89
SO_4^{2-}	100.34	0.76	98.25	0.67	0.41	0.43	100.22	1.78
NO_3^-	97.61	0.72	97.8	0.62	0.22	0.19	100.96	1.09
Cl^-	100.98	1.86	97.88	0.91	1.66	2.29	100.00	2.35
NH_4^+	98.63	1.76	100.14	3.04	3.61	4.22	96.86	11.30
Ca^{2+}	105.25	3.49	99.4	2.79	1.12	1.53	117.27	12.11
Mg^{2+}	103.97	3.26	99.06	2.79	1.51	2.12	102.40	9.71
Na^+	95.84	2.53	97.34	2.47	3.27	3.89	91.94	4.74
K^+	100.31	3.65	100.18	3.63	2.15	2.54	96.83	5.74
NO_2^-	NA	NA	99.01	0.57	1.42	2.57	NA	NA
Acidity	101.06	3.41	95.58	6.57	2.81*	1.66*	NA	NA

Note: NA = not analyzed.

*Replicated only for three quarters.

Source: QST.

Table 2-26. Laboratory Precision and Accuracy Results for Precipitation Concentration Data, 1989 to 1995 Total Grand Averages

Parameter	Reference Sample Recovery (%)		Continuing Verification Samples (%)		Replicate Percent Difference		Unknown Reference Check Samples (%)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
pH (as H^+)	105.34	4.48	97.54*	4.85*	2.81	3.97	104.82	9.21
Conductivity	102.21	2.97	100.64*	3.27*	1.16	1.57	100.5	4.48
SO_4^{2-}	100.73	1.09	98.81	1.34	0.55	0.74	100.94	1.58
NO_3^-	98.5	0.97	98.67	0.90	0.40	0.55	99.69	1.62
Cl^-	101.62	2.71	99.39	2.18	3.10	5.09	101.87	3.62
NH_4^+	99.20	2.17	99.26	3.21	3.12	4.56	97.86	6.95
Ca^{2+}	101.29	4.45	98.27	3.05	1.86	2.7	101.28	10.01
Mg^{2+}	102.26	3.45	97.96	3.25	1.68	2.03	100.77	5.61
Na^+	97.25	3.45	97.98	3.28	3.53	4.59	95.18	5.81
K^+	100.8	3.74	100.12	3.69	2.66	4.13	97.84	6.99
NO_2^-	NA	NA	99.22	0.86	1.67	2.99	NA	NA
Acidity	102.33	4.73	97.68**	5.04**	3.57	3.78	NA	NA

Note: NA = not analyzed.

*Analyzed from 1991 to 1995 only.
**Analyzed from 1990 to 1995 only.

Source: QST.

Table 3-1. Annual Mean Concentrations of SO_4^{2-} and SO_2 by Subregion*

	SO_4^{2-}									SO_2								
Region	1987	1988	1989	1990	1991	1992	1993	1994	1995	1987	1988	1989	1990	1991	1992	1993	1994	1995
Northeast	5.89	6.56	6.46	6.09	6.22	5.52	5.74	5.50	4.81	13.68	15.52	15.66	13.50	13.20	11.70	12.91	11.75	8.35
Upper Northeast	3.20	3.39	3.01	2.79	2.58	2.53	2.07	2.33	1.94	3.83	4.33	3.09	2.69	2.35	1.93	1.77	1.88	1.46
Midwest	5.78	5.99	6.85	6.07	6.07	5.30	5.39	5.64	5.17	16.81	14.46	13.83	12.79	12.20	10.71	11.57	11.83	8.16
Upper Midwest	ins	3.81	4.22	3.49	3.50	3.12	2.89	2.78	2.88	ins	5.18	5.29	4.56	3.94	3.52	3.60	3.50	2.64
South Central	7.50	6.04	6.40	6.23	5.75	5.41	5.90	5.28	5.37	13.23	10.45	7.84	6.88	6.10	5.97	7.08	6.24	4.82
Southern Periphery	ins	ins	5.04	4.74	4.08	3.99	4.33	4.22	4.16	ins	ins	3.46	2.62	2.42	2.41	2.88	2.29	1.80
All Eastern Sites	6.11	6.01	6.02	5.58	5.43	4.94	5.11	4.95	4.64	12.18	12.64	10.49	9.23	8.65	7.85	8.57	8.23	5.97
All Western Sites	ins	ins	0.88	0.83	0.82	0.86	0.89	0.87	0.83	ins	ins	0.75	0.73	0.63	0.56	0.69	0.75	0.69

Note: ins = Insufficient data; site must have been operational for 26 weeks during a year to be included on this table.

*All values in $\mu g/m^3$.

Source: QST.

Table 3-2. Annual Mean Concentrations of NO_3^- and NH_4^+ by Subregion*

	NO_3^-									NH_4^+								
Region	1987	1988	1989	1990	1991	1992	1993	1994	1995	1987	1988	1989	1990	1991	1992	1993	1994	1995
Northeast	1.09	0.78	0.97	0.73	0.72	0.75	0.71	0.71	0.90	--	--	2.08	1.82	1.91	1.74	1.74	1.68	1.62
Upper Northeast	0.29	0.27	0.26	0.20	0.22	0.19	0.22	0.22	0.22	--	--	0.84	0.74	0.71	0.62	0.50	0.61	0.57
Midwest	2.46	2.25	2.89	2.26	2.38	2.39	2.19	2.09	2.23	--	--	2.87	2.34	2.44	2.25	2.19	2.14	2.12
Upper Midwest	ins	1.38	1.71	1.73	1.61	1.41	1.37	1.55	1.35	--	--	1.82	1.49	1.50	1.38	1.25	1.23	1.25
South Central	0.66	0.57	0.65	0.52	0.62	0.50	0.51	0.63	0.68	--	--	1.89	1.75	1.72	1.63	1.72	1.56	1.70
Southern Periphery	ins	ins	0.57	0.41	0.53	0.45	0.49	0.47	0.47	--	--	1.38	1.18	1.18	1.13	1.21	1.14	1.08
All Eastern Sites	0.91	0.99	1.29	1.03	1.07	1.03	0.95	1.03	1.11	--	--	2.04	1.76	1.80	1.67	1.66	1.60	1.62
All Western Sites	0.28	ins	ins	0.24	0.28	0.26	0.29	0.23	0.18	--	--	0.35	0.31	0.31	0.31	0.31	0.30	0.29

Note: -- = NH_4^+ analysis began in August 1988 and is reported from January 1989.
ins = Insufficient data; site must have been operational for 26 weeks during a year to be included on this table.

*All values in $\mu g/m^3$.

Source: QST.

Table 3-3. Annual Mean Concentrations of HNO_3 and Total NO_3^- by Subregion*

	HNO_3									Total NO_3^-								
Region	1987	1988	1989	1990	1991	1992	1993	1994	1995	1987	1988	1989	1990	1991	1992	1993	1994	1995
Northeast	2.56	2.68	2.58	2.55	2.49	2.21	2.44	2.51	2.47	3.62	3.43	3.51	3.24	3.18	2.93	3.10	3.18	3.33
Upper Northeast	1.41	1.57	0.98	0.99	0.88	0.72	0.60	0.84	0.89	1.67	1.81	1.22	1.17	1.09	0.90	0.80	1.05	1.10
Midwest	2.07	2.55	2.56	2.43	2.45	2.23	2.41	2.65	2.64	4.50	4.80	5.41	4.66	4.78	4.58	4.56	4.70	4.84
Upper Midwest	ins	1.49	1.57	1.39	1.29	1.25	1.26	1.33	1.33	ins	2.91	3.24	3.10	2.89	2.64	2.60	2.86	2.66
South Central	2.86	2.43	2.17	2.14	1.83	1.83	2.04	2.03	2.22	3.48	2.98	2.79	2.63	2.42	2.31	2.51	2.63	2.86
Southern Periphery	ins	ins	1.39	1.41	1.22	1.17	1.30	1.35	1.42	ins	ins	1.95	1.79	1.73	1.61	1.77	1.81	1.87
All Eastern Sites	2.46	2.47	2.18	2.12	1.99	1.85	2.00	2.12	2.17	3.33	3.45	3.44	3.12	3.02	2.85	2.91	3.11	3.25
All Western Sites	ins	ins	0.57	0.50	0.45	0.48	0.45	0.55	0.52	ins	ins	0.85	0.74	0.72	0.73	0.74	0.77	0.69

Note: ins = Insufficient data; site must have been operational for 26 weeks during a year to be included on this table.

*All values in $\mu g/m^3$.

Source: QST.

Table 3-4. Results of Linear Regression Analysis on Annual and Seasonal SO_2 Concentrations

Average Statistics	Upper Northeast	Northeast	Upper Midwest	Midwest	South Central	Southern Periphery	West	East
Annual								
r-squared	0.92	0.65	0.83	0.75	0.69	0.60	0.29	0.83
p	0.0001	0.008	0.004	0.006	0.04	0.006	0.21	0.0007
slope	-0.37	-0.63	-0.48	-1.01	-0.87	-0.21	+0.02	-0.73
significant?	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Summer (Jun-Aug)								
r-squared	0.58	0.52	0.89	0.66	0.65	0.40	ND	ND
p	0.02	0.03	0.002	0.010	0.008	0.12	ND	ND
slope	-0.18	-0.47	-0.29	-1.13	-0.58	-0.12	ND	ND
significant?	Yes	Yes	Yes	Yes	Yes	No	ND	ND
Winter (Dec-Feb)								
r-squared	0.96	0.45	0.66	0.44	0.49	0.18	ND	ND
p	0.0001	0.05	0.03	0.07	0.03	0.34	ND	ND
slope	-0.71	-0.94	-0.33	-0.69	-1.78	-0.14	ND	ND
significant?	Yes	Yes	Yes	No	Yes	No	ND	ND

Note: ND = not determined.

Source: QST.

Table 3-5. Results of Linear Regression Analysis on Annual and Seasonal SO_4^{2-} Concentrations

Average Statistics	Upper Northeast	Northeast	Upper Midwest	Midwest	South Central	Southern Periphery	West	East
Annual								
r-squared	0.94	0.66	0.94	0.69	0.74	0.60	0.64	0.89
p	0.0001	0.008	0.0003	0.01	0.003	0.04	0.03	0.001
slope	-0.18	-0.15	-0.27	-0.23	-0.26	-0.16	+0.03	-0.21
significant?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Summer (Jun-Aug)								
r-squared	0.68	0.41	0.73	0.48	0.65	0.64	ND	ND
p	0.006	0.06	0.01	0.055	0.009	0.03	ND	ND
slope	-0.31	-0.22	-0.41	-0.45	-0.38	-0.36	ND	ND
significant?	Yes	No	Yes	No	Yes	Yes	ND	ND
Winter (Dec-Feb)								
r-squared	0.95	0.57	0.14	0.02	0.37	0.005	ND	ND
p	0.0001	0.02	0.40	0.74	0.08	0.88	ND	ND
slope	-0.14	-0.10	-0.05	+0.02	-0.19	-0.01	ND	ND
significant?	Yes	Yes	No	No	No	No	ND	ND

Note: ND = not determined.

Source: QST.

Table 3-6. Summary of SURE SO_4^{2-} Data

Annual 1978 SURE Concentrations ($\mu g/m^3$)	SURE Site	Annual 1994 CASTNet Concentrations ($\mu g/m^3$)	Corresponding CASTNet Site
9.01	2 (Scranton, PA)	5.3	144 (Washington's Crossing, NJ)
11.71	4 (Duncan Falls, OH)	6.4	114 (Deer Creek State Park, OH)
10.14	5 (Rockport, IN)	6.4	140 (Vincennes, IN)
9.03	7 (Fort Wayne, IN)	5.1	133 (Salamonie Reservoir, IN)
8.88	9 (Lewisburg, VA)	5.8	120 (Horton Station, VA)

Sources: Shreffler and Barnes, 1996; QST.

Table 3-7. Annual Average Deposition Velocities for SO_2 and HNO_3*

	SO_2									HNO_3								
Region	1987	1988	1989	1990	1991	1992	1993	1994	1995	1987	1988	1989	1990	1991	1992	1993	1994	1995
Northeast	0.308	0.303	0.315	0.333	0.332	0.337	0.338	0.341	0.343	1.616	1.555	1.628	1.775	1.743	1.810	1.887	1.904	1.877
Upper Northeast	0.286	0.279	0.299	0.308	0.308	0.301	0.306	0.328	0.321	1.321	1.591	1.604	1.798	1.781	1.690	1.594	1.938	1.759
Midwest	0.276	0.295	0.296	0.306	0.306	0.308	0.307	0.326	0.322	1.208	1.407	1.405	1.462	1.412	1.436	1.543	1.647	1.644
Upper Midwest	ins	0.251	0.293	0.298	0.300	0.308	0.302	0.303	0.310	ins	1.246	1.583	1.735	1.450	1.868	1.848	1.782	1.934
South Central	0.371	0.295	0.323	0.326	0.333	0.336	0.340	0.348	0.344	1.537	1.267	1.610	1.733	1.744	1.794	1.853	1.846	2.048
Southern Periphery	ins	0.200	0.293	0.322	0.322	0.326	0.330	0.322	0.352	ins	1.158	1.570	1.633	1.605	1.654	1.754	1.750	1.887
All Eastern Sites	0.331	0.295	0.307	0.319	0.322	0.324	0.326	0.334	0.335	1.556	1.412	1.561	1.677	1.646	1.704	1.768	1.811	1.835
All Western Sites	ins	ins	0.344	0.306	0.309	0.308	0.302	0.306	0.310	ins	ins	2.388	2.237	2.236	2.201	2.185	2.236	2.508

Note: ins=Insufficient data; a site must have 8 valid samples per season and 3 valid seasons per year to be included in summary statistics.

*All values in cm/sec.

Source: QST.

Table 3-8. Annual Average Deposition Velocities for O_3 and Particulates*

Region	O_3									Particulates								
	1987	1988	1989	1990	1991	1992	1993	1994	1995	1987	1988	1989	1990	1991	1992	1993	1994	1995
Northeast	0.151	0.157	0.169	0.184	0.183	0.187	0.181	0.186	0.187	0.108	0.087	0.098	0.107	0.108	0.106	0.112	0.114	0.118
Upper Northeast	0.169	0.128	0.150	0.155	0.154	0.151	0.160	0.171	0.166	0.060	0.079	0.095	0.110	0.102	0.098	0.094	0.115	0.104
Midwest	0.127	0.144	0.148	0.158	0.157	0.160	0.151	0.170	0.165	0.072	0.099	0.094	0.096	0.095	0.093	0.097	0.111	0.110
Upper Midwest	ins	0.105	0.141	0.141	0.145	0.147	0.138	0.142	0.143	ins	0.059	0.090	0.099	0.090	0.103	0.101	0.103	0.105
South Central	0.253	0.169	0.178	0.175	0.184	0.183	0.184	0.194	0.178	0.093	0.078	0.100	0.111	0.108	0.111	0.117	0.122	0.131
Southern Periphery	ins	0.055	0.160	0.187	0.196	0.193	0.189	0.181	0.211	ins	0.031	0.081	0.100	0.097	0.103	0.108	0.108	0.119
All Eastern Sites	0.193	0.154	0.162	0.170	0.174	0.174	0.171	0.179	0.177	0.098	0.086	0.096	0.105	0.103	0.104	0.108	0.115	0.116
All Western Sites	ins	ins	0.167	0.118	0.125	0.123	0.119	0.124	0.122	ins	ins	0.171	0.164	0.162	0.158	0.154	0.161	0.174

Note: ins=Insufficient data; a site must have 8 valid samples per season and 3 valid seasons per year to be included in summary statistics.

*All values in cm/sec.

Source: QST.

Table 3-9. Annual Average Dry Depositions for SO_2 and SO_4^{2-}*

	SO_2 as S									SO_4^{2-} as S								
Region	1987	1988	1989	1990	1991	1992	1993	1994	1995	1987	1988	1989	1990	1991	1992	1993	1994	1995
Northeast	5.415	6.928	6.598	6.826	6.389	5.684	6.215	5.922	4.190	0.768	0.636	0.705	0.675	0.737	0.634	0.677	0.653	0.595
Upper Northeast	ins	1.831	1.112	1.335	0.960	0.816	0.755	0.750	0.767	ins	0.294	0.318	0.329	0.286	0.267	0.214	0.220	0.255
Midwest	ins	9.334	5.977	6.078	5.684	5.048	5.262	6.304	4.521	ins	0.648	0.726	0.644	0.643	0.544	0.600	0.739	0.652
Upper Midwest	ins	ins	2.098	1.976	ins	1.506	1.686	1.530	1.348	ins	ins	0.431	0.351	ins	0.381	0.301	0.284	0.330
South Central	3.074	4.584	3.946	3.417	2.670	2.940	3.410	3.329	2.896	0.730	0.496	0.697	0.716	0.646	0.639	0.747	0.695	0.722
Southern Periphery	ins	ins	1.374	1.394	1.099	1.295	1.245	1.170	1.032	ins	ins	0.422	0.528	0.437	0.440	0.522	0.500	0.543
All Eastern Sites	4.635	5.903	4.502	4.651	4.382	3.730	4.061	4.166	3.182	0.755	0.554	0.622	0.623	0.624	0.552	0.608	0.615	0.583
All Western Sites	ins	ins	ins	0.351	0.324	0.270	0.330	0.445	0.182	ins	ins	ins	0.142	0.143	0.152	0.146	0.152	0.122

Note: ins=Insufficient data; a site must have 8 valid samples per season and 3 valid seasons per year to be included in summary statistics.

*All values in kg/ha (as sulfur).

Source: QST.

Table 3-10. Annual Average Dry Depositions for HNO_3 and NO_3^-*

	HNO_3 as N									NO_3^- as N								
Region	1987	1988	1989	1990	1991	1992	1993	1994	1995	1987	1988	1989	1990	1991	1992	1993	1994	1995
Northeast	3.312	3.002	3.042	3.140	3.125	2.793	3.189	3.562	3.315	0.077	0.035	0.072	0.054	0.050	0.048	0.056	0.055	0.068
Upper Northeast	ins	2.001	1.113	1.423	1.214	0.901	0.674	0.688	1.293	ins	0.015	0.017	0.019	0.016	0.014	0.014	0.015	0.021
Midwest	ins	2.732	2.534	2.605	2.564	2.339	2.712	3.273	3.192	ins	0.157	0.165	0.141	0.138	0.142	0.128	0.132	0.151
Upper Midwest	ins	ins	1.669	1.633	ins	1.782	1.551	1.518	1.736	ins	ins	0.103	0.103	ins	0.084	0.093	0.098	0.090
South Central	2.879	2.195	2.829	2.748	2.348	2.423	2.731	2.731	3.190	0.039	0.031	0.042	0.041	0.032	0.034	0.040	0.054	0.074
Southern Periphery	ins	ins	1.438	1.642	1.369	1.412	1.560	1.648	2.009	ins	ins	0.031	0.027	0.033	0.035	0.040	0.038	0.045
All Eastern Sites	3.168	2.546	2.428	2.583	2.470	2.254	2.523	2.728	2.846	0.064	0.049	0.082	0.071	0.065	0.065	0.064	0.073	0.085
All Western Sites	ins	ins	ins	0.781	0.753	0.770	0.718	0.896	0.734	ins	ins	ins	0.030	0.031	0.029	0.030	0.028	0.019

Note: ins=Insufficient data; a site must have 8 valid samples per season and 3 valid seasons per year to be included in summary statistics.

*All values in kg/ha (as nitrogen).

Source: QST.

Table 3-11. Annual Average Dry Depositions for NH_4^+*

Region	NH_4^+ as N								
	1987	1988	1989	1990	1991	1992	1993	1994	1995
Northeast	--	--	0.552	0.473	0.519	0.444	0.493	0.470	0.457
Upper Northeast	--	--	0.207	0.208	0.183	0.151	0.120	0.130	0.177
Midwest	--	--	0.665	0.559	0.565	0.512	0.532	0.593	0.582
Upper Midwest	--	--	0.425	0.337	ins	0.358	0.301	0.275	0.319
South Central	--	--	0.457	0.472	0.408	0.430	0.502	0.463	0.545
Southern Periphery	--	--	0.265	0.290	0.277	0.293	0.337	0.311	0.338
All Eastern Sites	--	--	0.490	0.454	0.454	0.415	0.449	0.447	0.463
All Western Sites	--	--	ins	0.121	0.122	0.128	0.117	0.118	0.105

Note: -- = NH_4^+ analysis began in August 1988 and is reported from January 1989.
ins = Insufficient data; a site must have 8 valid samples per season and 3 valid seasons per year to be included in summary statistics.

*All values in kg/ha (as nitrogen).

Source: QST.

Table 3-12. Results of Linear Regression Analysis on Annual and Seasonal SO_4^{2-} Concentrations in Precipitation

Average Statistics	Upper Northeast	Northeast	Upper Midwest	Midwest	South Central	Southern Periphery	West	East
Summer								
r-squared	0.07	0.01	0.47	0.26	0.08	0.16	0.02	0.10
p	0.56	0.85	0.09	0.24	0.55	0.36	0.76	0.48
slope	-0.03	-0.04	-0.15	-0.13	-0.08	-0.09	+0.01	-0.08
significant?	No	No	No	No	No	No	No	No
Winter								
r-squared	0.92	0.95	0.009	0.70	0.53	0.0003	0.20	0.91
p	0.0006	0.0002	0.84	0.02	0.06	0.97	0.31	0.001
slope	-0.12	-0.18	-0.02	-0.12	-0.08	-0.002	-0.05	-0.11
significant?	Yes	Yes	No	Yes	No	No	No	Yes
Annual								
r-squared	0.70	0.44	0.46	0.44	0.47	0.76	0.01	0.52
p	0.02	0.11	0.09	0.11	0.09	0.01	0.85	0.07
slope	-0.05	-0.09	-0.14	-0.13	-0.09	-0.04	+0.01	-0.09
significant?	Yes	No	No	No	No	Yes	No	No

Source: QST.

Table 3-13. Results of Linear Regression Analysis on Annual and Seasonal NO_3^- Concentrations in Precipitation

Average Statistics	Upper Northeast	Northeast	Upper Midwest	Midwest	South Central	Southern Periphery	West	East
Summer								
r-squared	0.33	0.04	0.02	0.002	0.01	0.01	0.04	0.002
p	0.17	0.66	0.74	0.92	0.84	0.85	0.65	0.92
slope	+0.03	+0.03	-0.02	-0.006	-0.01	-0.01	+0.03	+0.005
significant?	No	No	No	No	No	No	No	No
Winter								
r-squared	0.57	0.62	0.06	0.02	0.57	0.39	0.17	0.51
p	0.05	0.04	0.60	0.76	0.05	0.13	0.36	0.07
slope	-0.11	-0.07	-0.04	-0.02	-0.04	+0.04	-0.04	-0.04
significant?	Yes	Yes	No	No	Yes	No	No	No
Annual								
r-squared	0.20	0.05	0.23	0.09	0.29	0.01	0.003	0.18
p	0.32	0.62	0.28	0.51	0.21	0.83	0.91	0.34
slope	-0.01	-0.01	-0.08	-0.03	-0.02	+0.002	+0.003	-0.02
significant?	No	No	No	No	No	No	No	No

Source: QST.

Table 3-14. CDN Precipitation Mean Concentrations for SO_4^{2-} (mg/L) from 1990 through 1994

Region	Site No.	1990	1991	1992	1993	1994	5-Year Mean	STD	CV	%Diff.
Midwest	114	3.841	5.067	3.657	4.741	3.664	4.194	0.662	15.8	-4.6
	115	2.706	3.608	2.889	3.528	2.441	3.034	0.513	16.9	-9.8
	123	3.348	3.721	3.183	3.926	3.467	3.529	0.296	8.4	3.5
	157	2.732	5.352	4.666	3.735	2.932	3.883	1.121	28.9	7.3
Northeast	110	--	--	3.166	3.217	--	3.191	0.036	1.1	1.6
	119	3.595	3.661	3.186	3.171	3.487	3.420	0.229	6.7	3.0
	128	3.777	5.048	4.093	4.430	3.540	4.178	0.591	14.1	-6.3
	147	--	--	--	--	2.760	2.760	--	--	NA
	180	--	--	--	3.930	2.987	3.458	0.667	19.3	-24.0
South Central	108	3.820	3.071	2.706	2.264	2.422	2.857	0.621	21.7	-36.7
	111	2.849	3.409	2.474	2.258	2.277	2.653	0.485	18.3	-20.1
	125	--	2.076	2.513	3.167	2.392	2.537	0.459	18.1	15.2
	126	2.233	2.446	2.376	2.155	1.310	2.104	0.459	21.8	-41.3
	142	--	--	--	1.504	1.504	--	--	--	NA
Southern Periphery	156	2.011	2.068	1.506	1.486	1.324	1.679	0.337	20.1	-34.2
Upper Midwest	124	3.467	3.370	3.524	2.963	2.768	3.218	0.334	10.4	-20.2
	134	1.804	1.776	2.852	1.323	1.406	1.832	0.609	33.3	-22.1
West	161	1.240	0.598	0.766	0.690	0.922	0.843	0.252	29.8	-25.6
	162	1.181	0.862	1.360	1.388	--	1.198	0.242	20.2	17.5
	167	1.889	2.575	2.172	2.422	1.158	2.043	0.559	27.4	-38.7

Note: CV= coefficient of variation (STD/5-Year Average) × 100.
%Diff. = (End Year Average – Start Year Average/Start Year Average) × 100.
NA = not applicable.
STD = standard deviation.
-- = not operating and/or insufficient data.

Source: QST.

Table 3-15. CDN Precipitation Mean Concentrations for NO_3^- (mg/L) from 1990 through 1994

Region	Site No.	1990	1991	1992	1993	1994	5-Year Mean	STD	CV	%Diff.
Midwest	114	2.445	3.741	2.676	3.090	2.532	2.897	0.533	18.4	3.5
	115	2.154	3.243	2.665	2.770	2.217	2.610	0.445	17.0	2.9
	123	2.287	2.992	2.486	3.200	2.890	2.771	0.375	13.5	26.4
	157	1.539	3.339	2.525	2.172	1.916	2.298	0.684	29.8	24.5
Northeast	110	--	--	2.858	2.270	--	2.564	0.416	16.2	-20.6
	119	2.196	2.293	2.232	1.971	2.190	2.176	0.122	5.6	-0.3
	128	2.860	3.297	2.904	2.814	2.194	2.814	0.396	14.1	-23.3
	147	--	--	--	--	2.065	2.065	--	--	NA
	180	--	--	--	2.652	2.171	2.411	0.340	14.1	-18.1
South Central	108	2.397	1.908	2.009	1.322	1.674	1.862	0.399	21.4	-30.2
	111	1.337	1.684	1.452	1.222	1.203	1.380	0.197	14.3	-10.0
	125	--	1.412	1.694	1.855	1.496	1.614	0.200	12.4	6.0
	126	1.155	1.247	1.314	1.185	0.794	1.139	0.202	17.8	-31.3
	142	--	--	--	--	0.896	0.896	--	--	NA
Southern Periphery	156	1.220	1.027	0.991	0.985	0.905	1.026	0.118	11.5	-25.8
Upper Midwest	124	2.816	2.894	3.398	2.452	2.570	2.826	0.367	13.0	-8.7
	134	1.538	1.712	3.012	1.509	1.425	1.839	0.664	36.1	-7.4
West	161	1.502	0.777	0.853	0.902	1.363	1.079	0.329	30.5	-9.2
	162	1.694	1.094	1.860	1.598	--	1.561	0.330	21.1	-5.7
	167	1.198	1.532	1.265	1.362	1.046	1.281	0.182	14.2	-12.8

Note: CV= coefficient of variation (STD/5-YearAverage) × 100.
%Diff. = (End Year Average - Start Year Average/Start Year Average) × 100.
NA = not applicable.
STD= standard deviation.
-- = not operating and/or insufficient data.

Source: QST.

Table 3-16. CDN Precipitation Mean Concentrations for Cl^- (mg/L) from 1990 through 1994

Region	Site No.	1990	1991	1992	1993	1994	5-Year Mean	STD	CV	%Diff.
Midwest	114	0.258	0.323	0.208	0.254	0.184	0.245	0.054	21.9	-28.9
	115	0.156	0.253	0.153	0.214	0.295	0.214	0.062	28.8	89.1
	123	0.168	0.273	0.183	0.294	0.217	0.227	0.055	24.3	29.6
	157	0.231	0.368	0.298	0.279	0.195	0.274	0.066	24.2	-15.8
Northeast	110	--	--	0.233	0.178	--	0.205	0.039	18.9	-23.6
	119	0.259	0.195	0.167	0.167	0.216	0.201	0.038	19.1	-16.6
	128	0.396	0.325	0.341	0.299	0.261	0.324	0.050	15.5	-34.2
	147	--	--	--	--	0.438	0.438	--	--	NA
	180	--	--	--	0.232	0.174	0.203	0.041	20.1	-25.0
South Central	108	0.605	0.401	0.345	0.269	0.365	0.397	0.126	31.7	-39.6
	111	0.206	0.228	0.130	0.139	0.177	0.176	0.042	23.9	-14.1
	125	--	0.496	0.484	0.575	0.585	0.535	0.052	9.8	17.9
	126	0.143	0.167	0.112	0.146	0.110	0.136	0.024	18.0	-22.9
	142	--	--	--	--	1.831	1.831	--	--	NA
Southern Periphery	156	1.192	1.055	0.779	0.810	0.867	0.941	0.177	18.8	-27.3
Upper Midwest	124	0.206	0.194	0.255	0.189	0.141	0.197	0.041	20.6	-31.4
	134	0.097	0.087	0.138	0.089	0.079	0.098	0.023	23.6	-18.9
West	161	0.151	0.078	0.191	0.119	0.144	0.137	0.042	30.5	-4.6
	162	0.200	0.118	0.232	0.176	--	0.182	0.048	26.5	-13.6
	167	0.231	0.441	0.300	0.254	0.213	0.288	0.092	31.9	-7.8

Note: CV= coefficient of variation (STD/5-Year Average) × 100.
%Diff. = (End Year Average - Start Year Average/Start Year Average) × 100.
NA = not applicable.
STD = standard deviation.
-- = not operating and/or insufficient data.

Source: QST.

Table 3-17. CDN Precipitation Mean Concentrations for NH_4^+ (mg/L) from 1990 through 1994

Region	Site No.	1990	1991	1992	1993	1994	5-Year Mean	STD	CV	%Diff.
Midwest	114	0.602	0.681	0.581	0.577	0.526	0.594	0.056	9.5	-12.5
	115	0.465	0.710	0.581	0.644	0.571	0.594	0.091	15.4	22.7
	123	0.525	0.681	0.606	0.847	0.737	0.679	0.123	18.1	40.2
	157	0.556	1.231	1.087	0.796	0.566	0.847	0.305	36.0	1.6
Northeast	110	--	--	0.475	0.420	--	0.447	0.039	8.7	-11.6
	119	0.347	0.335	0.413	0.273	0.443	0.362	0.067	18.6	27.9
	128	0.514	0.635	0.699	0.693	0.477	0.604	0.103	17.0	-7.3
	147	--	--	--	--	0.377	0.377	--	--	NA
	180	--	--	--	0.534	0.331	0.432	0.144	22.2	-38.0
South Central	108	0.403	0.323	0.378	0.258	0.258	0.324	0.067	20.6	-35.9
	111	0.316	0.405	0.341	0.277	0.262	0.320	0.057	17.8	-16.9
	125	--	0.297	0.379	0.468	0.388	0.383	0.070	18.3	30.6
	126	0.277	0.329	0.324	0.236	0.184	0.270	0.061	22.7	-33.7
	142	--	--	--	--	0.159	0.159	--	--	NA
Southern Periphery	156	0.428	0.235	0.135	0.160	0.146	0.221	0.122	55.4	-65.9
Upper Midwest	124	0.716	0.718	0.967	0.600	0.719	0.744	0.135	18.1	0.4
	134	0.705	0.682	1.104	0.640	0.605	0.747	0.203	27.2	-14.1
West	161	0.289	0.131	0.136	0.188	0.201	0.189	0.064	33.8	-30.3
	162	0.377	0.292	0.503	0.379	--	0.388	0.087	22.5	0.5
	167	0.278	0.417	0.357	0.341	0.271	0.333	0.060	18.1	-2.6

Note: CV= coefficient of variation (STD/5-Year Average) × 100.
%Diff. = (End Year Average - Start Year Average/Start Year Average) × 100.
NA = not applicable.
STD = standard deviation.
-- = not operating and/or insufficient data.

Source: QST.

Table 3-18. CDN Precipitation Mean Concentrations for Ca^{2+} (mg/L) from 1990 through 1994

Region	Site No.	1990	1991	1992	1993	1994	5-Year Mean	STD	CV	%Diff.
Midwest	114	0.449	0.588	0.339	0.391	0.283	0.410	0.117	28.5	-37.1
	115	0.351	0.539	0.319	0.463	0.286	0.392	0.106	27.0	-18.4
	123	0.333	0.533	0.302	0.486	0.417	0.414	0.098	23.7	25.3
	157	0.313	0.795	0.560	0.403	0.334	0.481	0.200	41.6	6.8
Northeast	110	--	--	0.251	0.181	--	0.216	0.049	22.8	-27.9
	119	0.247	0.207	0.162	0.132	0.178	0.185	0.044	23.6	-27.8
	128	0.302	0.302	0.288	0.228	0.188	0.261	0.051	19.6	-37.7
	147	--	--	--	--	0.108	0.108	--	--	NA
	180	--	--	--	0.201	0.154	0.177	0.033	18.7	-23.4
South Central	108	0.259	0.222	0.135	0.079	0.110	0.161	0.077	47.5	-57.6
	111	0.206	0.283	0.184	0.134	0.130	0.188	0.063	33.4	-36.9
	125	--	0.145	0.182	0.196	0.146	0.168	0.026	15.4	0.7
	126	0.117	0.140	0.141	0.111	0.055	0.113	0.035	31.2	-53.5
	142	--	--	--	--	0.148	0.148	--	--	NA
Southern Periphery	156	0.145	0.162	0.112	0.124	0.120	0.132	0.020	15.4	-17.2
Upper Midwest	124	0.623	0.572	0.807	0.777	0.306	0.617	0.200	32.5	-50.9
	134	0.392	0.381	0.723	0.181	0.331	0.401	0.198	49.4	-15.5
West	16	0.610	0.253	0.395	0.267	0.321	0.369	0.146	39.5	-47.4
	162	0.510	0.411	0.546	0.428	--	0.474	0.065	13.7	-16.1
	167	0.470	0.867	0.441	0.518	0.238	0.507	0.228	44.9	-49.4

Note: CV= coefficient of variation (STD/5-Year Average) × 100.
%Diff. = (End Year Average - Start Year Average/Start Year Average) × 100.
NA = not applicable.
STD = standard deviation.
-- = not operating and/or insufficient data.

Source: QST.

Table 3-19. CDN Precipitation Mean Concentrations for Na^+ (mg/L) from 1990 through 1994

Region	Site No.	1990	1991	1992	1993	1994	5-Year Mean	STD	CV	%Diff.
Midwest	114	0.101	0.121	0.080	0.218	0.066	0.117	0.060	51.3	-34.8
	115	0.072	0.110	0.050	0.139	0.148	0.104	0.042	40.5	105.0
	123	0.069	0.119	0.071	0.187	0.077	0.105	0.050	48.1	10.6
	157	0.104	0.144	0.114	0.172	0.084	0.123	0.034	27.9	-18.5
Northeast	110	--	--	0.085	0.116	--	0.101	0.021	21.3	36.5
	119	0.092	0.056	0.042	0.075	0.066	0.066	0.019	28.5	-29.1
	128	0.199	0.141	0.153	0.180	0.112	0.157	0.034	21.5	-43.5
	147	--	--	--	--	0.217	0.217	--	--	NA
	180	--	--	--	0.126	0.051	0.089	0.053	59.4	-59.5
South Central	108	0.351	0.224	0.178	0.168	0.179	0.220	0.076	34.6	-49.0
	111	0.104	0.121	0.060	0.111	0.080	0.095	0.025	26.2	-23.1
	125	--	0.286	0.255	0.401	0.305	0.312	0.063	20.3	6.6
	126	0.066	0.084	0.055	0.143	0.056	0.081	0.037	45.6	-15.5
	142	--	--	--	--	1.014	1.014	--	--	NA
Southern Periphery	156	0.655	0.600	0.408	0.467	0.477	0.521	0.102	19.6	-27.2
Upper Midwest	124	0.093	0.078	0.104	0.142	0.057	0.095	0.032	33.7	-39.0
	134	0.049	0.046	0.072	0.095	0.046	0.062	0.022	34.9	-5.1
West	161	0.117	0.104	0.120	0.132	0.074	0.109	0.022	20.2	-36.6
	162	0.110	0.080	0.133	0.164	--	0.122	0.036	29.3	49.1
	167	0.134	0.363	0.208	0.237	0.114	0.211	0.099	46.7	-14.8

Note: CV= coefficient of variation (STD/5-Year Average) × 100.
%Diff. = (End Year Average - Start Year Average/Start Year Average) × 100.
NA = not applicable.
STD = standard deviation.
-- = not operating and/or insufficient data.

Source: QST.

Table 3-20. CDN Precipitation Mean Concentrations for Mg^{2+} (mg/L) from 1990 through 1994

Region	Site No.	1990	1991	1992	1993	1994	5-Year Mean	STD	CV	%Diff.
Midwest	114	0.092	0.110	0.055	0.076	0.055	0.078	0.024	30.5	-40.3
	115	0.061	0.113	0.077	0.132	0.058	0.088	0.033	37.0	-5.7
	123	0.060	0.099	0.056	0.102	0.084	0.080	0.022	27.2	40.3
	157	0.038	0.095	0.073	0.061	0.046	0.063	0.023	36.0	21.2
Northeast	110	--	--	0.043	0.036	--	0.039	0.005	11.5	-16.3
	119	0.042	0.035	0.029	0.021	0.037	0.033	0.008	24.6	-10.0
	128	0.045	0.043	0.047	0.044	0.035	0.043	0.005	11.2	-22.3
	147	--	--	--	--	0.041	0.041	--	--	NA
	180	--	--	--	0.042	0.027	0.034	0.011	31.2	-35.7
South Central	108	0.065	0.043	0.036	0.024	0.034	0.040	0.015	37.4	-47.1
	111	0.029	0.037	0.026	0.021	0.023	0.027	0.006	22.4	-18.7
	125	--	0.046	0.052	0.067	0.051	0.054	0.009	16.4	10.9
	126	0.021	0.027	0.028	0.023	0.014	0.022	0.006	25.1	-33.7
	142	--	--	--	--	0.128	0.128	--	--	NA
Southern Periphery	156	0.110	0.082	0.060	0.062	0.069	0.077	0.021	26.8	-37.1
Upper Midwest	124	0.124	0.118	0.148	0.136	0.061	0.117	0.034	28.7	-51.4
	134	0.054	0.056	0.108	0.027	0.046	0.058	0.030	51.9	-14.7
West	161	0.063	0.028	0.037	0.036	0.035	0.040	0.014	34.4	-44.3
	162	0.063	0.046	0.068	0.056	--	0.058	0.010	16.5	-11.1
	167	0.047	0.090	0.050	0.052	0.033	0.055	0.021	38.9	-29.5

Note: CV= coefficient of variation (STD/5-Year Average) × 100.
%Diff. = (End Year Average - Start Year Average/Start Year Average) × 100.
NA = not applicable.
STD = standard deviation.
-- = not operating and/or insufficient data.

Source: QST.

Table 3-21. CDN Precipitation Mean Concentrations for K^+ (mg/L) from 1990 through 1994

Region	Site No.	1990	1991	1992	1993	1994	5-Year Mean	STD	CV	%Diff.
Midwest	114	0.073	0.065	0.040	0.075	0.046	0.060	0.016	27.0	-37.6
	115	0.031	0.049	0.043	0.106	0.200	0.086	0.070	81.5	542.2
	123	0.033	0.097	0.033	0.148	0.087	0.080	0.048	60.6	160.1
	157	0.041	0.206	0.118	0.109	0.044	0.103	0.068	65.3	7.7
Northeast	110	--	--	0.071	0.081	--	0.076	0.007	9.0	14.1
	119	0.082	0.067	0.126	0.055	0.071	0.080	0.028	34.4	-12.7
	128	0.039	0.040	0.048	0.078	0.039	0.049	0.017	34.1	-0.8
	147	--	--	--	--	0.037	0.037			NA
	180	--	--	--	0.108	0.046	0.077	0.044	57.0	-57.4
South Central	108	0.060	0.059	0.047	0.042	0.039	0.049	0.010	20.2	-35.8
	111	0.026	0.055	0.036	0.046	0.140	0.061	0.045	75.0	431.5
	125	--	0.044	0.073	0.151	0.057	0.081	0.048	59.2	29.6
	126	0.024	0.053	0.036	0.042	0.030	0.037	0.011	31.0	26.0
	142	--	--	--	--	0.068	0.068	--	--	NA
Southern Priphery	156	0.266	0.061	0.038	0.055	0.053	0.095	0.096	101.9	-80.0
Upper Midwest	124	0.042	0.052	0.062	0.074	0.035	0.053	0.015	29.1	-15.6
	134	0.040	0.038	0.052	0.037	0.043	0.042	0.006	14.2	7.8
West	161	0.056	0.028	0.046	0.042	0.062	0.046	0.013	28.4	10.3
	162	0.043	0.032	0.051	0.067	--	0.049	0.015	30.1	55.8
	167	0.056	0.109	0.073	0.227	0.080	0.109	0.069	63.0	42.3

Note: CV= coefficient of variation (STD/5-Year Average) × 100.
%Diff. = (End Year Average − Start Year Average/Start Year Average) × 100.
NA = not applicable.
STD = standard deviation.
-- = not operating and/or insufficient data.

Source: QST.

Table 3-22. CDN Precipitation Mean Concentrations for H^+ [milliequavalent per liter (μeq/L)] from 1990 through 1994

Region	Site No.	1990	1991	1992	1993	1994	5-Year Mean	STD	CV	%Diff.
Midwest	114	56.627	0.355	59.251	69.256	65.472	66.192	9.356	14.1	15.6
	115	44.568	58.349	45.546	42.564	35.350	45.276	8.327	18.4	-20.7
	123	54.583	52.040	47.949	48.663	46.279	49.903	3.352	6.7	-15.2
	157	34.946	44.384	50.847	37.716	41.147	41.808	6.177	14.8	17.7
Northeast	110	--	--	62.834	58.816	--	60.825	2.841	4.7	-6.4
	119	64.575	83.203	65.632	66.117	68.030	69.511	7.756	11.2	5.4
	128	66.044	85.126	64.828	70.158	62.154	69.662	9.113	13.1	-5.9
	147	--	--	--	--	56.222	56.222	--	--	NA
	180	--	--	--	69.655	63.395	66.525	4.426	6.7	-9.0
South Central	108	63.797	64.575	50.457	42.178	48.668	53.935	9.856	18.3	-23.7
	111	47.811	46.772	41.653	36.065	39.886	42.437	4.883	11.5	-16.6
	125	--	38.000	40.034	41.204	38.213	39.363	1.529	3.9	0.6
	126	41.229	41.171	39.878	35.443	25.188	36.582	6.794	18.6	-38.9
	142	--	--	--	--	23.283	23.283	--	--	NA
Southern Periphery	156	22.863	26.350	26.125	24.300	20.547	24.037	2.415	10.0	-10.1
Upper Midwest	124	36.666	40.885	33.548	32.473	28.720	34.458	4.579	13.3	-21.7
	134	11.224	14.184	24.403	13.361	10.829	14.800	5.550	37.5	-3.5
West	161	7.346	10.397	23.891	5.976	11.707	11.863	7.105	59.9	59.4
	162	9.859	6.742	8.054	5.966	--	7.655	1.703	22.3	-39.5
	167	12.902	18.664	15.713	14.557	12.824	14.932	2.410	16.1	-0.6

Note: CV= coefficient of variation (STD/5-Year Average) × 100.
%Diff. = (End Year Average - Start Year Average/Start Year Average) × 100.
NA = not applicable.
STD = standard deviation.
-- = not operating and/or insufficient data.

Source: QST.

Table 3-23. CDN Mean Wet Deposition Data for SO_4^{2-} (kg/ha) from 1990 through 1994

Region	Site No.	1990	1991	1992	1993	1994	5-Year Mean	STD	CV	%Diff.
Midwest	114	33.783	27.268	26.080	30.153	29.950	29.447	2.985	10.1	-11.3
	115	21.427	22.165	22.198	27.483	18.414	22.338	3.269	14.6	-14.1
	123	33.506	20.872	29.426	20.791	21.780	25.275	5.846	23.1	-35.0
	157	23.237	21.631	21.462	32.796	16.529	23.131	5.959	25.8	-28.9
Northeast	110	--	--	28.524	25.971	--	27.248	1.805	6.6	-9.0
	119	36.079	31.764	32.317	28.738	31.149	32.009	2.653	8.3	-13.7
	128	29.246	23.842	26.344	38.833	26.145	28.882	5.884	0.4	-10.6
	147	--	--	--	--	18.103	18.103	--	--	NA
	180	--	--	--	28.342	26.495	27.418	1.306	4.8	-6.5
South Central	108	13.553	17.262	16.835	20.996	19.383	17.606	2.819	16.0	43.0
	111	28.892	29.478	19.099	23.573	22.336	24.676	4.433	18.0	-22.7
	125	--	15.556	17.283	22.496	20.559	18.974	3.134	16.5	32.2
	126	5.093	26.050	30.144	20.063	21.325	24.535	4.012	16.4	-15.0
	142	--	--	--	--	12.841	12.841	--	--	NA
Southern Periphery	156	12.036	16.705	16.728	12.437	15.297	14.645	2.269	15.5	26.9
Upper Midwest	124	18.397	22.018	21.921	15.802	15.887	18.805	3.071	16.3	-13.6
	134	16.261	15.953	14.541	10.363	7.746	12.973	3.751	28.9	-52.4
West	161	3.184	2.411	2.457	2.585	2.118	2.551	0.393	15.4	-33.5
	162	3.186	2.936	2.747	2.337	--	2.801	0.358	12.8	26.7
	167	5.943	5.350	5.294	5.091	3.383	5.012	0.964	19.2	-43.1

Note: CV= coefficient of variation (STD/5-Year Average) × 100.
%Diff. = (End Year Average - Start Year Average/Start Year Average) × 100.
NA = not applicable.
STD = standard deviation.
-- = not operating and/or insufficient data.

Source: QST.

Table 3-24. CDN Mean Wet Deposition Data for NO_3^- (kg/ha) from 1990 through 1994

Region	Site No.	1990	1991	1992	1993	1994	5-Year Mean	STD	CV	%Diff.
Midwest	114	18.437	18.137	16.216	19.480	17.977	18.049	1.180	6.5	-2.5
	115	15.484	16.823	17.436	20.712	14.224	16.936	2.449	14.5	-8.1
	123	19.813	15.074	18.544	16.110	15.041	16.916	2.157	12.7	-24.1
	157	13.018	11.584	11.372	18.421	9.239	12.727	3.457	27.2	-29.0
Northeast	110	--	--	20.822	18.198	--	19.510	1.855	9.5	-12.6
	119	19.832	18.770	19.391	18.163	18.719	18.975	0.647	3.4	-5.6
	128	18.965	15.679	17.473	25.082	16.358	18.712	3.772	20.2	-13.7
	147	--	--	--	--	14.177	14.177	--	--	NA
	180	--	--	--	18.465	17.757	18.111	0.501	2.8	-3.8
South Central	108	8.127	10.456	10.003	12.009	11.563	10.432	1.522	14.6	42.3
	111	12.972	14.232	10.466	12.218	10.936	12.165	1.527	12.6	-15.7
	125	--	10.739	10.816	13.055	12.764	11.843	1.237	10.4	18.9
	126	13.266	13.743	15.178	10.843	11.590	12.924	1.731	13.4	-12.6
	142	--	--	--	--	7.069	7.069	--	--	NA
Southern Periphery	156	6.766	10.806	10.579	7.931	9.908	9.198	1.769	19.2	46.4
Upper Midwest	124	12.091	17.031	17.606	11.997	12.471	14.239	2.824	19.8	3.1
	134	12.924	13.327	11.988	10.025	7.487	11.150	2.412	21.6	-42.1
West	161	3.639	2.884	2.891	3.249	3.388	3.210	0.326	10.2	-6.9
	162	4.662	3.864	3.616	2.954	--	3.774	0.706	18.7	-36.6
	167	4.400	3.629	3.455	3.674	3.457	3.723	0.391	10.5	-21.4

Note: CV = coefficient of variation (STD/5-Year Average) × 100.
%Diff. = (End Year Average - Start Year Average/Start Year Average) × 100.
NA = not applicable.
STD = standard deviation.
-- = not operating and/or insufficient data.

Source: QST.

Table 3-25. CDN Mean Wet Deposition Data for Cl^- (kg/ha) from 1990 through 1994

Region	Site No.	1990	1991	1992	1993	1994	5-Year Mean	STD	CV	%Diff.
Midwest	114	1.875	1.627	1.389	1.398	1.359	1.530	0.221	14.4	-27.5
	115	1.009	1.163	0.988	1.550	1.884	1.319	0.388	29.4	86.7
	123	1.555	1.180	1.251	1.376	1.004	1.273	0.207	16.3	-35.4
	157	1.721	1.467	1.431	2.344	1.097	1.612	0.466	28.9	-36.2
Northeast	110	--	--	1.363	1.440	--	1.401	0.054	3.9	5.7
	119	1.993	1.677	1.489	1.487	1.762	1.681	0.211	12.6	-11.6
	128	4.458	1.511	2.664	3.562	1.994	2.838	1.189	41.9	-55.3
	147	--	--	--	--	4.411	4.411	--	--	NA
	180	--	--	--	1.801	1.555	1.678	0.175	10.4	-13.7
South Central	108	2.583	2.076	2.645	2.471	3.199	2.595	0.404	15.6	23.9
	111	2.043	2.384	0.986	1.335	1.523	1.654	0.559	33.8	-25.4
	125	--	3.189	3.821	3.658	4.588	3.814	0.581	15.2	43.9
	126	1.862	1.802	1.394	1.199	1.621	1.576	0.278	17.7	-13.0
	142	--	--	--	--	21.537	21.537	--	--	NA
Southern Periphery	156	7.963	8.853	8.846	7.340	9.897	8.580	0.974	11.4	24.3
Upper Midwest	124	0.845	1.051	1.074	0.916	0.681	0.913	0.161	17.6	-19.5
	134	0.858	0.625	0.569	0.503	0.431	0.597	0.163	27.3	-49.8
West	161	0.391	0.285	0.344	0.357	0.373	0.350	0.040	11.5	-4.7
	162	0.431	0.387	0.397	0.309	--	0.381	0.052	13.6	-28.3
	167	0.818	1.019	0.688	0.588	0.741	0.771	0.162	21.0	-9.4

Note: CV= coefficient of variation (STD/5-Year Average) × 100.
%Diff. = (End Year Average - Start Year Average/Start Year Average) × 100.
NA = not applicable.
STD = standard deviation.
-- = not operating and/or insufficient data.

Source: QST.

Table 3-26. CDN Mean Wet Deposition Data for NH_4^+(kg/ha) from 1990 through 1994

Region	Site No.	1990	1991	1992	1993	1994	5-Year Mean	STD	CV	%Diff.
Midwest	114	3.740	3.476	3.268	4.732	3.511	3.746	0.577	15.4	-6.1
	115	3.577	4.230	3.736	4.960	3.618	4.024	0.584	14.5	1.2
	123	4.463	3.744	4.523	4.652	3.898	4.256	0.407	9.6	-12.7
	157	3.806	4.219	4.444	6.577	2.861	4.381	1.369	31.2	24.8
Northeast	110	--	--	3.514	2.969	--	3.241	0.385	11.9	-15.5
	119	.199	2.836	3.649	2.522	3.554	3.152	0.476	15.1	11.1
	128	4.465	3.268	4.266	6.171	3.555	4.345	1.134	26.1	-20.4
	147	--	--	--	--	2.317	2.317	--	--	NA
	180	--	--	--	4.180	2.726	3.453	1.028	29.8	-34.8
South Central	108	1.393	1.826	2.084	2.480	2.153	1.987	0.406	20.4	54.5
	111	2.906	3.503	2.387	2.589	2.421	2.761	0.463	16.8	-16.7
	125	--	2.148	2.373	2.995	2.865	2.595	0.401	15.5	33.4
	126	3.026	3.619	3.738	2.336	3.071	3.158	0.559	17.7	1.5
	142	--	--	--	--	1.443	1.443	--	--	NA
Southern Periphery	156	2.247	1.891	1.418	1.343	1.882	1.756	0.374	21.3	-16.2
Upper Midwest	124	3.319	4.862	4.646	3.076	3.431	3.867	0.823	21.3	3.4
	134	6.093	5.346	4.411	3.707	3.787	4.669	1.032	22.1	-37.8
West	161	0.736	0.524	0.510	0.680	0.510	0.592	0.108	18.2	-30.7
	162	0.990	1.119	0.984	0.747	--	0.960	0.155	16.1	-24.6
	167	1.101	1.062	1.233	0.853	0.894	1.028	0.156	15.2	-18.9

Note: CV= coefficient of variation (STD/5-Year Average) × 100.
%Diff. = (End Year Average - Start Year Average/Start Year Average) × 100.
NA = not applicable.
STD = standard deviation.
-- = not operating and/or insufficient data.

Source: QST.

Table 3-27. CDN Mean Wet Deposition Data for Ca^{2+} (kg/ha) from 1990 through 1994

Region	Site No.	1990	1991	1992	1993	1994	5-Year Mean	STD	CV	%Diff.
Midwest	114	2.186	2.508	1.445	1.817	1.624	1.916	0.430	22.4	-25.7
	115	1.822	2.382	1.793	3.301	1.590	2.178	0.693	31.8	-12.7
	123	1.962	2.078	1.857	2.301	1.754	1.991	0.211	10.6	-10.6
	157	1.935	2.728	1.742	3.111	1.326	2.168	0.733	33.8	-31.5
Northeast	110	--	--	1.510	1.115	--	1.312	0.279	21.3	-26.2
	119	1.587	1.775	1.412	1.066	1.330	1.434	0.267	18.6	-16.2
	128	.297	1.123	1.104	1.648	1.396	1.314	0.223	17.0	7.7
	147	--	--	--	--	0.680	0.680	--	--	NA
	180	--	--	--	1.144	1.187	1.165	0.030	2.6	3.8
South Central	108	0.675	0.690	0.629	0.671	0.619	0.657	0.031	4.7	-8.3
	111	1.499	1.678	1.012	1.028	0.949	1.233	0.331	26.9	-36.7
	125	--	0.833	0.743	0.915	0.815	0.827	0.071	8.5	-2.2
	126	1.211	1.305	1.230	0.820	0.866	1.086	0.226	20.8	-28.5
	142	--	--	--	--	0.974	0.974	--	--	NA
Southern Periphery	156	0.790	1.117	0.995	0.867	1.150	0.984	0.156	15.8	45.6
Upper Midwest	124	2.098	2.968	2.835	3.403	1.263	2.514	0.842	33.5	-39.8
	134	2.700	2.525	1.884	1.183	1.843	2.027	0.606	29.9	-31.7
West	161	1.828	0.793	0.722	0.744	0.642	0.946	0.496	52.5	-64.9
	162	1.193	1.203	0.812	0.635		0.961	0.283	29.5	-46.8
	167	1.379	1.397	0.832	0.842	0.546	0.999	0.375	37.5	-60.4

Note: CV= coefficient of variation (STD/5-Year Average) × 100.
%Diff. = (End Year Average - Start Year Average/Start Year Average) × 100.
NA = not applicable.
STD = standard deviation.
-- = not operating and/or insufficient data.

Source: QST.

Table 3-28. CDN Mean Wet Deposition Data for Na^+ (kg/ha) from 1990 through 1994

Region	Site No.	1990	1991	1992	1993	1994	5-Year Mean	STD	CV	%Diff.
Midwest	114	0.744	0.613	0.501	0.707	0.506	0.614	0.112	18.2	-32.0
	115	0.347	0.462	0.324	0.947	0.961	0.608	0.320	52.6	177.0
	123	0.620	0.522	0.477	0.714	0.451	0.557	0.109	19.6	-27.3
	157	0.684	0.614	0.536	1.369	0.450	0.731	0.367	50.3	-34.2
Northeast	110	--	--	0.444	0.767	--	0.606	0.228	37.7	72.8
	119	0.703	0.533	0.391	0.575	0.710	0.583	0.132	22.7	1.0
	128	2.051	0.559	1.036	1.724	0.877	1.250	0.618	49.5	-57.2
	147	--	--	--	--	2.151	2.151	--	--	NA
	180	--	--	--	0.889	0.517	0.703	0.263	37.4	-41.8
South Central	108	1.315	0.954	1.188	1.275	1.561	1.259	0.220	17.4	18.7
	111	0.919	1.184	0.409	0.730	0.716	0.792	0.286	36.1	-22.1
	125	--	1.628	1.896	2.039	2.321	1.971	0.289	14.7	42.6
	126	0.857	0.861	0.622	0.789	0.817	0.789	0.098	12.4	-4.7
	142	--	--	--	--	11.660	11.660	--	--	NA
Southern Periphery	156	4.119	4.766	4.478	4.000	4.995	4.472	0.421	9.4	21.3
Upper Midwest	124	0.348	0.377	0.353	0.602	0.296	0.395	0.119	30.2	-15.0
	134	0.415	0.325	0.260	0.376	0.251	0.325	0.072	22.0	-39.7
West	161	0.295	0.238	0.200	0.320	0.200	0.251	0.055	21.8	-32.2
	162	0.225	0.225	0.205	0.280	--	0.234	0.032	13.9	24.4
	167	0.434	0.715	0.396	0.433	0.369	0.469	0.140	29.8	-15.0

Note: CV= coefficient of variation (STD/5-Year Average) × 100.
%Diff. = (End Year Average – Start Year Average/Start Year Average) × 100.
NA = not applicable.
STD = standard deviation.
-- = not operating and/or insufficient data.

Source: QST.

Table 3-29. CDN Mean Wet Deposition Data for Mg^{2+} (kg/ha) from 1990 through 1994

Region	Site No.	1990	1991	1992	1993	1994	5-Year Mean	STD	CV	%Diff.
Midwest	114	0.438	0.465	0.276	0.381	0.312	0.374	0.080	21.4	-28.7
	115	0.356	0.501	0.397	0.941	0.302	0.499	0.258	51.6	-15.2
	123	0.347	0.401	0.351	0.496	0.375	0.394	0.061	15.5	7.9
	157	0.269	0.349	0.255	0.483	0.221	0.315	0.105	33.3	-17.8
Northeast	110	--	--	0.273	0.223		0.248	0.035	14.2	-18.3
	119	0.288	0.289	0.252	0.186	0.274	0.258	0.043	16.7	-4.9
	128	0.371	0.185	0.253	0.408	0.254	0.294	0.092	31.3	-31.6
	147	--	--	--	--	0.347	0.347	--	--	NA
	180	--	--	--	0.271	0.221	0.246	0.035	14.3	-18.5
South Central	108	0.221	0.184	0.235	0.227	0.258	0.225	0.027	12.0	16.8
	111	0.247	0.293	0.161	0.179	0.180	0.212	0.056	26.4	-27.2
	125	--	0.280	0.326	0.339	0.371	0.329	0.038	11.5	32.5
	126	0.264	0.271	0.273	0.186	0.213	0.241	0.039	16.3	-19.3
	142	--	--	--	--	1.431	1.431	--	--	NA
Southern Periphery	156	0.637	0.683	0.649	0.544	0.715	0.645	0.065	10.0	12.2
Upper Midwest	124	0.416	0.623	0.581	0.599	0.264	0.497	0.153	30.9	-36.5
	134	.395	0.383	0.312	0.170	0.273	0.307	0.091	29.8	-30.9
West	161	0.181	0.098	0.092	0.104	0.082	0.112	0.040	35.4	-54.5
	162	0.153	0.153	0.113	0.091	--	0.128	0.031	24.3	-37.7
	167	0.146	0.173	0.104	0.103	0.088	0.123	0.035	28.8	-39.8

Note: CV= coefficient of variation (STD/5-Year Average) × 100.
%Diff. = (End Year Average – Start Year Average/Start Year Average) × 100.
NA = not applicable.
STD = standard deviation.
-- = not operating and/or insufficient data.

Source: QST.

Table 3-30. CDN Mean Wet Deposition Data for K^+ (kg/ha) from 1990 through 1994

Region	Site No.	1990	1991	1992	1993	1994	5-Year Mean	STD	CV	%Diff.
Midwest	114	0.296	0.288	0.237	0.325	0.314	0.292	0.034	11.6	6.2
	115	0.202	0.288	0.265	0.729	1.171	0.531	0.414	78.0	479.4
	123	0.304	0.326	0.227	0.692	0.377	0.385	0.179	46.6	23.9
	157	0.299	0.528	0.382	0.997	0.272	0.496	0.297	60.0	-9.0
Northeast	110	--	--	0.482	0.532	--	0.507	0.035	6.9	10.4
	119	0.464	0.501	0.771	0.396	0.676	0.562	0.156	27.8	45.7
	128	0.263	0.186	0.216	0.679	0.301	0.329	0.201	61.0	14.3
	147	--	--	--	--	0.249	0.249	--	--	NA
	180	--	--	--	0.843	0.407	0.625	0.308	49.3	-51.7
South Central	108	0.216	0.205	0.315	0.375	0.319	0.286	0.073	25.6	47.4
	111	0.241	0.461	0.203	0.307	0.795	0.401	0.241	60.1	230.0
	125	--	0.286	0.343	0.518	0.401	0.387	0.099	25.6	40.2
	126	0.262	0.507	0.365	0.320	0.492	0.389	0.107	27.6	88.1
	142	--	--	--	--	0.619	0.619	--	--	NA
Southern Periphery	156	1.047	0.449	0.378	0.477	0.650	0.600	0.269	44.8	-37.9
Upper Midwest	124	0.160	0.274	0.284	0.367	0.181	0.253	0.084	33.2	13.5
	134	0.362	0.255	0.188	0.229	0.229	0.252	0.066	26.0	-36.6
West	161	0.143	0.104	0.081	0.155	0.183	0.133	0.041	30.7	28.0
	162	0.087	0.105	0.088	0.102		0.095	0.009	9.6	17.2
	167	0.162	0.210	0.166	0.295	0.260	0.219	0.058	26.7	60.7

Note: CV= coefficient of variation (STD/5-Year Average) × 100.
%Diff. = (End Year Average - Start Year Average/Start Year Average) × 100.
NA = not applicable.
STD = standard deviation.
-- = not operating and/or insufficient data.

Source: QST.

Table 3-31. CDN Mean Wet Deposition Data for H^+ (kg/ha) from 1990 through 1994

Region	Site No.	1990	1991	1992	1993	1994	5-Year Mean	STD	CV	%Diff.
Midwest	114	0.620	0.480	0.489	0.511	0.579	0.536	0.061	11.4	-6.6
	115	0.364	0.376	0.383	0.339	0.296	0.352	0.035	10.0	-18.6
	123	0.618	0.332	0.523	0.278	0.345	0.419	0.144	34.4	-44.2
	157	0.379	0.241	0.284	0.396	0.232	0.306	0.077	25.1	-38.8
Northeast	110	--	--	0.583	0.534	--	0.559	0.034	6.2	-8.4
	119	0.772	0.726	0.668	0.632	0.658	0.691	0.057	8.2	-14.8
	128	0.562	0.494	0.493	0.700	0.488	0.548	0.090	16.5	-13.2
	147	--	--	--	--	0.387	0.387	--	--	NA
	180	--	--	--	0.506	0.572	0.539	0.047	8.7	13.0
South Central	108	0.266	0.390	0.322	0.426	0.392	0.359	0.064	17.9	47.1
	111	0.537	0.537	0.354	0.435	0.401	0.453	0.082	18.1	-25.4
	125	--	0.320	0.328	0.403	0.385	0.359	0.041	11.5	20.3
	126	0.492	0.502	0.557	0.368	0.378	0.459	0.083	18.0	-23.3
	142	--	--	--	--	0.214	0.214	--	--	NA
Southern Periphery	156	0.162	0.331	0.336	0.219	0.270	0.263	0.074	28.2	66.2
Upper Midwest	124	0.271	0.288	0.313	0.191	0.229	0.258	0.049	18.9	-15.5
	134	0.123	0.155	0.164	0.127	0.048	0.123	0.046	37.1	-61.2
West	161	0.023	0.044	0.086	0.027	0.040	0.044	0.025	56.5	73.7
	162	0.034	0.023	0.025	0.018	--	0.025	0.007	26.3	-47.1
	167	0.056	0.055	0.054	0.059	0.043	0.053	0.006	11.6	-23.2

Note: CV= coefficient of variation (STD/5-Year Average) × 100.
%Diff. = (End Year Average − Start Year Average/Start Year Average) × 100.
NA = not applicable.
STD = standard deviation.
-- = not operating and/or insufficient data.

Source: QST.

Table 3-32. CDN Mean Wet Deposition Data for SO_4^{2-} as S (kg/ha) from 1990 through 1994

Region	Site No.	1990	1991	1992	1993	1994	5-Year Mean	STD	CV	%Diff.
Midwest	114	11.277	9.102	8.705	10.065	9.997	9.829	0.996	10.1	-11.3
	115	7.152	7.399	7.410	9.174	6.147	7.456	1.091	14.6	-14.1
	123	11.184	6.967	9.822	6.940	7.270	8.437	1.951	23.1	-35.0
	157	7.756	7.221	7.164	10.947	5.517	7.721	1.989	25.8	-28.9
Northeast	110	--	--	9.521	8.669	--	9.095	0.603	6.6	-9.0
	119	12.043	10.603	10.787	9.593	10.397	10.685	0.886	8.3	-13.7
	128	9.762	7.959	8.793	12.963	8.727	9.641	1.964	20.4	-10.6
	147	--	--	--	--	6.043	6.043	--	--	NA
	180	--	--	--	9.460	8.844	9.152	0.436	4.8	-6.5
South Central	108	4.524	5.762	5.620	7.008	6.470	5.877	0.941	16.0	43.0
	111	9.644	9.840	6.375	7.869	7.456	8.237	1.480	18.0	-22.7
	125	--	5.192	5.769	7.509	6.863	6.333	1.046	16.5	32.2
	126	8.376	8.696	10.062	6.697	7.118	8.190	1.339	16.4	-15.0
	142	--	--	--	--	4.286	4.286	--	--	NA
Southern Periphery	156	4.024	5.576	5.584	4.151	5.106	4.888	0.757	15.5	26.9
Upper Midwest	124	6.141	7.349	7.317	5.275	5.303	6.277	1.025	16.3	-13.6
	134	5.428	5.325	4.854	3.459	2.586	4.330	1.252	28.9	-52.4
West	161	1.063	0.805	0.820	0.863	0.707	0.852	0.131	15.4	-33.5
	162	1.064	0.980	0.917	0.780	--	0.935	0.120	12.8	-26.7
	167	1.984	1.786	1.767	1.699	1.129	1.673	0.322	19.2	-43.1

Note: CV= coefficient of variation (STD/5-Year Average) × 100.
%Diff. = (End Year Average - Start Year Average/Start Year Average) × 100.
NA = not applicable.
STD = standard deviation.
-- = not operating and/or insufficient data.

Source: QST.

Table 3-33. CDN Mean Wet Deposition Data for NO_3^- as N (kg/ha) from 1990 through 1994

Region	Site No.	1990	1991	1992	1993	1994	5-Year Mean	STD	CV	%Diff.
Midwest	114	4.165	4.097	3.663	4.401	4.061	4.077	0.267	6.5	-2.5
	115	3.498	3.800	3.939	4.679	3.213	3.826	0.553	14.5	-8.1
	123	4.476	3.405	4.189	3.639	3.398	3.821	0.487	12.7	-24.1
	157	2.941	2.617	2.569	4.161	2.087	2.875	0.781	27.2	-29.0
Northeast	110	--	--	4.704	4.111	--	4.407	0.419	9.5	-12.6
	119	4.480	4.240	4.381	4.103	4.229	4.286	0.146	3.4	-5.6
	128	4.284	3.542	3.947	5.666	3.695	4.227	0.852	20.2	-13.7
	147	--	--	--	--	3.203	3.203	--	--	NA
	180	--	--	--	4.171	4.011	4.091	0.113	2.8	-3.8
South Central	108	1.836	2.362	2.260	2.713	2.612	2.357	0.344	14.6	42.3
	111	2.930	3.215	2.364	2.760	2.470	2.748	0.345	12.6	-15.7
	125	--	2.426	2.443	2.949	2.883	2.675	0.279	10.4	18.8
	126	2.997	3.105	3.429	2.449	2.618	2.919	0.391	13.4	-12.6
	142	--	--	--	--	1.597	1.597	--	--	NA
Southern Periphery	156	1.528	2.441	2.390	1.792	2.238	2.078	0.400	19.2	46.4
Upper Midwest	124	2.731	3.847	3.977	2.710	2.817	3.217	0.638	19.8	3.1
	134	2.920	3.011	2.708	2.265	1.691	2.519	0.545	21.6	-42.1
West	161	0.822	0.651	0.653	0.734	0.765	0.725	0.074	10.2	-6.9
	162	1.053	0.873	0.817	0.667	--	0.853	0.159	18.7	-36.7
	167	0.994	0.820	0.781	0.830	0.781	0.841	0.088	10.5	-21.4

Note: CV= coefficient of variation (STD/5-Year Average) × 100.
%Diff. = (End Year Average − Start Year Average/Start Year Average) × 100.
NA = not applicable.
STD = standard deviation.
-- = not operating and/or insufficient data.

Source: QST.

Table 3-34. Results of Linear Regression Analysis for Wet Deposition of SO_4^{2-} as S and NO_3^- as N Using Annual Averages of Combined CDN/NADP Data

Average Statistics	Upper Northeast	Northeast	Upper Midwest	Midwest	South Central	Southern Periphery	West	East
Sulfur								
r-squared	0.77	0.571	0.283	0.644	0.73	0.454	0.417	0.726
p	0.01	0.05	0.22	0.03	0.01	0.10	0.12	0.01
slope	-0.321	-0.552	-0.277	-0.456	-0.367	-0.173	-.035	-0.418
significant?	Yes	Yes	No	Yes	Yes	No	No	Yes
Nitrogen								
r-squared	0.487	0.429	0.263	0.167	0.350	0.036	0.513	0.506
p	0.08	0.11	0.24	0.36	0.16	0.68	0.07	0.07
slope	-0.089	-0.133	-0.081	-0.063	-0.054	-0.019	-0.08	-0.026
significant?	No	No	No	No	No	No	No	No

Source: QST.

Table 3-35. Subregional Averages of Total Sulfur Deposition by Year and Percentages of Dry Deposition

	Total Deposition - S (kg/ha)							Percent Dry Deposition						
Region	1989	1990	1991	1992	1993	1994	1995	1989	1990	1991	1992	1993	1994	1995
Northeast	17.1	18.1	15.3	14.9	16.3	15.3	10.9	41.6	40.4	44.7	41.1	41.2	43.0	45.4
Upper Northeast	6.8	6.3	6.4	6.1	6.0	6.1	5.2	17.2	17.7	13.1	15.0	16.1	15.9	14.7
Midwest	16.3	16.3	13.7	13.3	15.0	13.1	11.3	39.7	39.1	43.5	38.9	39.0	44.9	42.6
Upper Midwest	6.9	8.7	ins	8.2	7.5	6.4	5.0	32.5	26.8	ins	23.0	26.4	28.4	29.0
South Central	14.5	11.9	10.7	10.5	11.5	11.3	9.9	36.1	36.5	33.4	36.3	38.0	35.5	40.8
Southern Periphery	7.4	7.3	6.7	6.3	6.4	7.1	5.7	24.4	26.2	23.0	27.3	27.5	23.4	27.8
All Western Sites	ins	1.8	1.8	1.5	1.7	1.7	1.1	ins	34.9	33.6	33.6	37.1	46.8	21.8
All Eastern Sites	13.4	13.7	12.1	11.4	12.2	11.3	9.1	37.2	37.2	39.4	36.5	37.4	38.4	39.8

Note: ins = Insufficient data.

Source: QST.

Table 3-36. Subregional Averages of Total Nitrogen Deposition by Year and Percentages of Dry Deposition

	Total Deposition - N (kg/ha)							Percent Dry Deposition						
Region	1989	1990	1991	1992	1993	1994	1995	1989	1990	1991	1992	1993	1994	1995
Northeast	7.6	7.7	6.9	6.7	7.6	7.5	7.1	43.1	41.1	45.8	42.3	42.4	47.3	51.8
Upper Northeast	3.9	3.1	3.3	3.1	3.3	3.3	3.3	20.0	20.3	18.8	18.2	21.0	21.6	21.7
Midwest	6.3	6.5	5.9	5.8	6.9	6.2	6.5	41.2	42.2	45.9	42.8	41.3	50.7	51.3
Upper Midwest	4.8	5.0	ins	5.4	4.8	4.4	4.5	38.4	34.7	ins	34.6	34.0	37.0	40.9
South Central	6.6	5.6	5.3	5.2	5.7	5.6	6.6	49.9	53.7	49.6	51.1	52.1	51.1	59.5
Southern Periphery	4.0	6.1	3.8	3.6	3.8	4.4	4.2	36.7	41.0	36.6	40.0	41.5	37.9	48.5
All Western Sites	ins	1.7	1.7	1.5	1.4	1.7	1.2	ins	49.3	50.3	54.5	47.1	57.4	38.2
All Eastern Sites	6.1	6.1	5.6	5.5	6.0	5.7	5.9	42.1	43.9	44.9	43.3	43.3	46.7	50.5

Note: ins = Insufficient data.

Source: QST.

Table 3-37. Annual Averages of Ozone Concentrations (ppb) by Region/Site

Region	Site	1987	1988	1989	1990	1991	1992	1993	1994	1995
Northeast	103/104	30	30	29	27	29	25	31	ins	ins
	106	30	34	29	33	33	30	33	33	32
	107	ins	35	30	30	30	27	30	30	30
	110	27	40	38	37	39	35	40	39	40
	112	ins	ins	37	35	38	33	34	34	37
	113	ins	37	32	31	34	29	31	32	35
	116	ins	ins	26	25	27	24	26	24	29
	117	ins	34	28	29	31	27	29	30	32
	119	ins	29	24	25	26	23	25	25	27
	128	ins	39	36	36	38	32	35	37	36
	144	ins	ins	29	29	31	26	29	28	34
	147	ins	ins	ins	ins	ins	ins	ins	35	36
Upper Northeast	105	34	36	38	37	37	34	37	ins	ins
	109	ins	ins	32	30	31	30	27	30	29
	132	ins	ins	ins	ins	ins	ins	29	31	31
	135	ins	ins	32	30	32	31	30	33	34
Midwest	114	ins	21	31	33	32	29	31	30	34
	115	ins	28	32	31	31	28	27	30	31
	122	22	37	33	32	33	29	30	32	32
	123	ins	ins	34	33	34	31	32	32	34
	130	ins	36	33	31	31	26	28	30	34
	133	ins	24	35	33	33	30	25	33	37
	136	ins	ins	ins	ins	ins	ins	30	39	43
	138	ins	ins	ins	ins	ins	ins	ins	35	38
	140	20	32	30	30	30	27	27	30	30
	146	22	29	26	24	24	22	19	ins	ins
	157	ins	25	33	32	31	30	29	31	34
	181	ins	ins	ins	ins	ins	ins	ins	ins	2
	572	ins	ins	ins	ins	ins	ins	ins	39	40
Upper Midwest	124	--	27	35	34	34	30	30	33	34
	134	--	26	35	32	33	32	32	34	35
	149	ins	33	37	32	34	31	31	32	36
South Central	101	30	27	ins	ins	ins	ins	ins	ins	ins
	102	36	36	ins	ins	ins	ins	ins	ins	ins
	108	ins	34	33	34	33	31	34	33	34
	111	ins	ins	27	31	29	27	28	30	33
	118	ins	50	45	46	46	39	45	45	46
	120	46	48	44	45	44	40	45	42	45
	121	ins	29	22	22	22	19	21	ins	ins
	125	ins	ins	ins	30	36	36	38	35	38

Table 3-37. Continued, Page 2 of 2

Region	Site	1987	1988	1989	1990	1991	1992	1993	1994	1995
South Central (continued)	126	ins	ins	45	48	45	43	44	42	46
	127	ins	27	34	38	36	31	34	33	37
	129/131	30	41	36	38	36	35	36	38	42
	137	ins	33	28	30	26	27	29	28	29
	139	ins	ins	ins	ins	ins	ins	ins	ins	54
	142	ins	ins	ins	ins	ins	ins	ins	35	33
	152	ins	ins	36	40	34	32	35	32	39
	153	ins	34	34	41	35	33	35	33	39
	571	ins	ins	ins	ins	ins	ins	ins	39	41
Southern Periphery	150	ins	23	28	27	25	24	26	24	28
	151	ins	ins	37	39	36	34	34	36	41
	156	ins	ins	31	32	30	31	31	29	32
West	161	45	ins	43	44	45	43	45	47	46
	162	45	ins	43	45	46	45	48	ins	ins
	163	37	ins	32	39	38	38	38	ins	ins
	164	43	ins	43	43	43	42	45	ins	ins
	165	46	ins	46	43	47	46	45	48	46
	167	41	ins	40	41	42	40	41	43	38
	168	22	ins	24	25	24	21	21	23	21
	169	48	ins	47	46	48	47	48	52	48
	174	47	ins	47	47	46	46	45	49	46
All Eastern Sites		30.6	34.3	33.7	33.0	32.9	31.5	31.5	32.8	33.0
All Western Sites		--	--	41.1	41.5	42.0	40.9	41.3	43.7	48.0

Note: ins = Insufficient data; sites must be 75-percent complete per quarter/year to be included in this table.

Source: QST.

Table 3-38. Annual Maxima of Ozone Concentrations (ppb) by Region/Site

Region	Site	1987	1988	1989	1990	1991	1992	1993	1994	1995
Northeast	103/104	162	212	125	150	149	144	129	ins	ins
	106	120	143	104	120	117	104	122	104	112
	107	ins	156	107	123	99	89	122	103	100
	110	79	126	101	93	109	102	109	98	96
	112	ins	ins	102	101	112	106	102	88	97
	113	ins	144	117	105	116	110	121	118	110
	116	ins	ins	131	137	156	118	134	141	166
	117	ins	156	110	109	118	96	109	111	116
	119	ins	134	109	116	111	91	123	105	98
	128	ins	155	112	124	122	105	125	113	119
	144	ins	ins	159	148	143	139	126	134	146
	147	ins	ins	ins	ins	ins	ins	137	151	ins
	175	ins	ins	ins	ins	ins	ins	ins	92	105
Upper Northeast	105	117	129	93	115	122	115	72	ins	ins
	ins	ins	109	91	86	98	100	81	85	78
	132	ins	ins	ins	ins	ins	ins	91	93	101
	135	ins	ins	103	88	99	93	77	84	80
	145	ins	ins	ins	ins	ins	ins	ins	91	103
Midwest	114	ins	57	157	115	107	98	111	113	116
	115	ins	115	109	111	101	126	128	99	107
	122	85	164	109	116	113	100	124	106	116
	123	ins	ins	110	103	120	104	103	103	110
	130	ins	121	104	106	145	98	91	105	119
	133	ins	73	109	110	107	103	78	109	118
	136	ins	ins	ins	ins	ins	ins	76	131	119
	138	ins	ins	ins	ins	ins	ins	ins	99	102
	140	81	119	112	110	112	103	99	103	108
	146	107	146	126	97	132	131	73	ins	ins
	157	ins	99	133	148	117	106	120	118	129
	181	ins	ins	ins	ins	ins	ins	ins	ins	2
	572	ins	ins	ins	ins	ins	ins	ins	102	136
Upper Midwest	124	ins	126	113	105	111	98	125	108	104
	134	ins	71	85	74	79	95	84	80	89
	149	ins	134	107	98	106	96	93	99	113
South Central	101	118	137	121	ins	ins	ins	ins	ins	ins
	102	117	132	ins	ins	ins	ins	ins	ins	ins
	108	ins	125	105	107	108	123	116	106	101
	111	ins	ins	95	117	108	96	118	107	115
	118	ins	160	95	103	114	99	102	101	107
	120	127	145	98	97	108	92	97	99	99

Table 3-38. Continued, Page 2 of 2

Region	Site	1987	1988	1989	1990	1991	1992	1993	1994	1995
South Central (continued)	121	ins	128	98	85	96	100	87	ins	ins
	125	ins	ins	ins	85	118	102	107	108	118
	126	ins	ins	103	110	95	97	98	106	96
	127	ins	62	90	109	98	99	118	101	91
	129/131	84	143	102	108	109	97	108	110	108
	137	ins	145	94	85	86	93	85	89	93
	139	ins	ins	ins	ins	ins	ins	ins	ins	117
	142	ins	ins	ins	ins	ins	ins	ins	94	97
	152	ins	ins	97	117	99	101	114	95	128
	153	ins	119	118	144	123	117	109	119	136
	571	ins	ins	ins	ins	ins	ins	ins	104	107
Southern Periphery	150	ins	67	102	94	87	88	92	94	95
	151	ins	ins	149	100	110	90	90	98	103
	156	ins	ins	84	93	90	88	81	92	86
West	161	ins	ins	84	88	86	73	88	88	80
	162	ins	ins	75	74	88	78	89	ins	ins
	163	ins	ins	66	80	73	73	67	ins	ins
	164	ins	ins	80	78	91	79	84	ins	ins
	165	ins	ins	79	74	76	72	71	78	83
	167	ins	ins	89	138	83	76	79	78	69
	168	ins	ins	67	66	62	77	58	61	54
	169	ins	ins	88	78	81	74	74	86	74
	174	ins	ins	80	92	81	81	77	84	64

Note: ins = Insufficient data; sites must be 75-percent complete per quarter/year to be included in this table.

Source: QST.

Table 3-39. Ozone Exceedances by Year (1988 to 1995)

Region	Site	1988			1989			1990			1991			1992			1993			1994			1995		
		≥80	≥100	≥125	≥80	≥100	≥125	≥80	≥100	≥125	≥80	≥100	≥125	≥80	≥100	≥125	≥80	≥100	≥125	≥80	≥100	≥125	≥80	≥100	≥125
Northeast	103	50	33	14	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins
	104	47	30	13	23	4	1	30	7	1	35	13	1	23	3	1	29	11	1	ins	ins	ins	ins	ins	ins
	106	46	23	7	16	2	0	31	7	0	52	9	0	18	2	0	39	8	0	28	2	0	24	5	0
	107	45	24	6	21	3	0	20	2	0	23	0	0	2	0	0	25	3	0	20	1	0	24	1	0
	110	43	17	1	21	1	0	15	0	0	33	2	0	12	1	0	16	4	0	10	0	0	14	0	0
	112	ins	ins	ins	22	1	0	17	2	0	31	6	0	10	1	0	23	1	0	11	0	0	16	0	0
	113	56	31	6	29	5	0	26	4	0	49	11	0	17	3	0	37	6	0	33	2	0	29	6	0
	116	ins	ins	ins	ins	14	2	51	17	2	75	35	6	37	11	0	68	21	1	56	15	3	49	20	2
	117	67	32	12	21	3	0	25	1	0	43	3	0	5	0	0	30	4	0	25	2	0	29	4	0
	119	53	24	4	21	1	0	26	4	0	36	6	0	9	0	0	29	4	0	23	2	0	21	0	0
	128	41	23	7	33	7	0	42	8	0	56	15	0	21	1	0	47	10	1	39	3	0	42	4	0
	144	ins	ins	ins	ins	17	3	49	17	3	63	31	7	36	11	2	58	14	1	49	16	3	58	18	2
Upper Northeast	105	29	7	2	11	0	0	17	5	0	30	11	0	15	4	0	0	0	0	ins	ins	ins	ins	ins	ins
	109	ins	ins	ins	4	0	0	3	0	0	6	0	0	8	1	0	2	0	0	3	0	0	0	0	0
	135	ins	ins	ins	2	1	0	2	0	0	4	0	0	4	0	0	0	0	0	1	0	0	1	0	0
Midwest	114	0	0	0	34	7	1	40	7	0	43	8	0	13	0	0	31	5	0	35	5	0	34	2	0
	115	9	3	0	24	3	0	23	6	0	33	4	0	18	4	1	8	1	1	12	0	0	19	4	0
	122	65	28	6	42	10	0	45	7	0	47	11	0	13	1	0	26	5	0	38	8	0	36	2	0
	123	ins	ins	ins	35	3	0	28	1	0	46	14	0	22	2	0	17	1	0	26	2	0	21	1	0
	130	61	15	0	35	3	0	25	5	0	31	6	1	8	0	0	7	0	0	30	1	0	36	5	0
	133	0	0	0	30	5	0	28	5	0	34	2	0	15	2	0	0	0	0	26	4	0	33	5	0
	140	63	20	0	27	2	0	31	5	0	27	7	0	16	1	0	12	0	0	34	4	0	32	4	0
	146	55	16	3	28	3	1	18	0	0	28	8	1	19	1	1	0	0	0	ins	ins	ins	ins	ins	ins
	157	6	0	0	45	7	1	42	7	2	44	10	0	24	2	0	17	3	0	39	6	0	37	9	1
Upper Midwest	124	6	3	1	23	3	0	19	3	0	28	3	0	11	0	0	8	1	1	9	1	0	18	2	0
	134	0	0	0	2	0	0	0	0	0	0	0	0	3	0	0	2	0	0	1	0	0	5	0	0
	149	24	5	2	31	3	0	15	0	0	30	7	0	13	0	0	8	0	0	13	0	0	18	2	0
South Central	101	50	23	5	31	3	0	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins
	102	57	18	1	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins	ins
	108	25	11	1	17	1	0	22	3	0	22	2	0	15	1	0	36	2	0	24	2	0	19	1	0
	111	ins	ins	ins	9	0	0	32	7	0	15	2	0	11	0	0	19	1	0	17	3	0	26	3	0
	118	33	13	2	26	0	0	29	1	0	31	2	0	10	0	0	31	2	0	19	1	0	33	2	0

Table 3-39. Continued, Page 2 of 2

Region	Site	1988			1989			1990			1991			1992			1993			1994			1995		
		≥80	≥100	≥125	≥80	≥100	≥125	≥80	≥100	≥125	≥80	≥100	≥125	≥80	≥100	≥125	≥80	≥100	≥125	≥80	≥100	≥125	≥80	≥100	≥125
South Central (continued)	120	66	26	7	27	0	0	30	0	0	22	1	0	5	0	0	27	0	0	22	0	0	26	0	0
	121	41	11	1	11	0	0	4	0	0	4	0	0	4	1	0	3	0	0	ins	ins	ins	ins	ins	ins
	125	ins	ins	ins	ins	ins	ins	1	0	0	9	2	0	14	3	0	34	4	0	15	1	0	17	1	0
	126	ins	ins	ins	15	1	0	21	3	0	6	0	0	6	0	0	14	0	0	9	1	0	18	0	0
	127	0	0	0	6	0	0	29	1	0	24	0	0	7	0	0	18	2	0	6	1	0	12	0	0
	129/131	52	24	3	26	2	0	23	3	0	26	2	0	9	0	0	18	1	0	28	3	0	37	6	0
	137	26	9	2	2	0	0	5	0	0	4	0	0	4	0	0	4	0	0	5	0	0	5	0	0
	152	ins	ins	ins	26	0	0	58	7	0	13	0	0	13	1	0	28	2	0	13	0	0	28	5	1
	153	15	10	0	14	4	0	62	27	2	28	5	0	21	3	0	37	5	0	17	5	0	42	11	2
Southern Periphery	150	0	0	0	5	1	0	13	0	0	9	0	0	4	0	0	8	0	0	14	0	0	13	0	0
	151	ins	ins	ins	11	2	1	17	1	0	14	2	0	8	0	0	4	0	0	8	0	0	25	1	0
	156	ins	ins	ins	5	0	0	3	0	0	5	0	0	6	0	0	3	0	0	7	0	0	3	0	0
West	161	ins	ins	ins	0	0	0	3	0	0	2	0	0	0	0	0	2	0	0	1	0	0	1	0	0
	162	ins	ins	ins	0	0	0	0	0	0	2	0	0	0	0	0	2	0	0	ins	ins	ins	ins	ins	ins
	163	ins	ins	ins	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	ins	ins	ins	ins	ins	ins
	164	ins	ins	ins	1	0	0	0	0	0	5	0	0	0	0	0	1	0	0	ins	ins	ins	ins	ins	ins
	165	ins	ins	ins	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	167	ins	ins	ins	1	0	0	3	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	168	ins	ins	ins	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	169	ins	ins	ins	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	174	ins	ins	ins	1	0	0	3	0	0	1	0	0	1	0	0	0	0	0	3	0	0	0	0	0

Note: Monthly sums adjusted for missing data and rolling sum set to missing if at least 1 month is missing.

Source: QST.

Table 3-40. Maximum Annual 3-Month Rolling SUM06 of Ozone Concentrations by Region/Site

Region	Site	1988		1989		1990		1991		1992		1993		1994		1995	
		Maximum	Period	Maximum	Period	Maximum	Period	Maximum	Period	Maximum	Period	Maximum	Period	Maximum	Period	Maximum	Period
Northeast	103/104	42.3	JunAug	20.5	MayJul	19.3	JunAug	28.0	MayJul	14.7	JunAug	23.4	JunAug	--	--	--	--
	106	44.1	JunAug	18.3	MayJul	27.8	JunAug	42.8	MayJul	23.8	MayJul	33.2	JunAug	30.0	JunAug	31.9	JunAug
	107	47.3	JunAug	21.0	MayJul	22.1	JunAug	32.4	MayJul	15.2	MayJul	27.4	MayJul	25.3	AprJun	26.3	JunAug
	110	36.2	MayJul	21.6	MayJul	15.6	AprJun	30.8	MayJul	18.4	MayJul	14.8	MarMay	19.5	MayJul	17.7	JunAug
	112	--	--	27.5	MayJul	22.1	JunAug	34.0	MayJul	20.1	MayJul	21.7	JunAug	18.2	JunAug	19.9	JunAug
	113	47.7	MayJul	30.4	JunAug	26.4	JunAug	45.5	MayJul	21.1	MayJul	30.5	JunAug	29.4	JunAug	29.5	JunAug
	116	--	--	36.1	JunAug	40.3	JunAug	50.0	JunAug	30.7	JunAug	45.8	JunAug	36.7	JunAug	36.5	JunAug
	117	53.5	JunAug	25.8	JunAug	25.4	JunAug	37.6	JunAug	17.9	MayJul	28.7	MayJul	24.9	JunAug	29.6	JunAug
	119	44.6	JunAug	14.8	AprJun	17.8	JunAug	28.0	MayJul	13.9	AprJun	22.5	JunAug	22.9	AprJun	16.4	JunAug
	128	47.2	JulSep	36.6	JunAug	36.1	JunAug	51.9	JunAug	26.5	JunAug	42.1	JunAug	40.0	JunAug	39.2	JunAug
	144	--	--	33.5	MayJul	35.8	JunAug	44.7	JunAug	28.6	JunAug	39.7	JunAug	36.5	MayJul	41.1	JunAug
	147	--	--	--	--	--	--	--	--	--	--	--	--	23.6	JunAug	25.3	JunAug
	175	--	--	--	--	--	--	--	--	--	--	--	--	19.0	JunAug	25.8	JunAug
Upper Northeast	105	19.0	MayJul	12.2	MayJul	12.0	MayJul	15.4	MayJul	12.3	AprJun	--	MarMay	--	--	--	--
	109	--	--	9.7	AprJun	9.0	MayJul	9.9	AprJun	10.0	AprJun	3.7	AprJun	5.0	AprJun	5.7	JunAug
	132	--	--	--	--	--	--	--	--	--	--	5.5	JunAug	5.8	MayJul	8.0	MayJul
	135	--	--	4.3	MayJul	3.5	AprJun	4.2	AprJun	6.5	AprJun	3.9	MarMay	2.5	MayJul	3.2	JunAug
	145	--	--	--	--	--	--	--	--	--	--	--	--	21.3	JunAug	17.8	JunAug
Midwest	114	--	MarMay	36.0	JunAug	34.5	JunAug	43.3	JunAug	23.8	MayJul	34.1	JunAug	31.2	JunAug	37.3	JunAug
	115	18.2	JulSep	28.7	JunAug	24.0	JunAug	37.1	MayJul	19.3	MayJul	10.6	MayJul	19.3	MayJul	20.7	JunAug
	122	60.1	MayJul	35.9	JunAug	35.8	JunAug	45.3	JunAug	21.4	MayJul	27.1	JunAug	34.7	JunAug	34.2	JunAug
	123	--	--	36.6	JunAug	29.0	JunAug	46.6	MayJul	26.5	MayJul	23.5	JunAug	31.0	JunAug	27.7	JunAug
	130	59.1	MayJul	36.5	JunAug	27.2	JunAug	38.8	JunAug	21.2	AprJun	14.3	MayJul	29.9	MayJul	37.4	JunAug
	133	--	MarMay	36.8	MayJul	28.2	JunAug	38.2	JunAug	22.8	MayJul	2.9	JunAug	28.6	MayJul	36.9	JunAug
	136	--	--	--	--	--	--	--	--	--	--	7.6	AugOct	29.0	AprJun	31.9	JulSep
	138	--	--	--	--	--	--	--	--	--	--	--	--	21.6	AprJun	25.7	MayJul
	140	56.3	MayJul	30.0	MayJul	30.5	JunAug	37.7	JunAug	22.4	AprJun	20.1	JunAug	30.5	JunAug	32.6	JunAug
	146	48.6	MayJul	27.0	JunAug	18.0	JunAug	33.7	JunAug	17.4	MayJul	--	MarMay	--	--	--	--
	157	13.1	AugOct	38.3	JunAug	35.5	JunAug	39.3	JunAug	28.9	MayJul	18.7	JunAug	30.5	JunAug	38.2	JunAug
	572	--	--	--	--	--	--	--	--	--	--	--	--	35.3	JunAug	46.3	JunAug
Upper Midwest	124	24.5	JulSep	28.7	MayJul	18.7	JunAug	27.7	MayJul	16.9	MayJul	9.0	JunAug	15.1	MayJul	21.1	JunAug
	134	--	MarMay	10.7	MayJul	6.2	MayJul	11.5	AprJun	15.2	MayJul	4.1	MarMay	7.6	AprJun	17.3	MayJul
	149	29.0	JulSep	24.0	JunAug	10.7	MayJul	23.1	MayJul	17.6	MayJul	7.8	MayJul	17.0	MayJul	21.0	MayJul

Table 3-40. Continued, Page 2 of 2

Region	Site	1988		1989		1990		1991		1992		1993		1994		1995	
		Maximum	Period	Maximum	Period	Maximum	Period	Maximum	Period	Maximum	Period	Maximum	Period	Maximum	Period	Maximum	Period
South Central	101	50.7	MayJul	28.0	MayJul	--	--	--	--	--	--	--	--	--	--	--	--
	102	47.4	MayJul	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	108	42.3	JunAug	24.8	AprJun	22.9	JunAug	26.3	MayJul	22.0	MayJul	35.9	JunAug	31.9	AprJun	18.7	JunAug
	111	--	--	11.8	JulSep	33.2	JunAug	20.5	JunAug	20.2	AprJun	23.3	JunAug	26.8	AprJun	27.6	JulSep
	118	50.7	JulSep	34.8	MayJul	33.8	JunAug	42.0	MayJul	22.9	MayJul	37.9	MayJul	29.5	AprJun	32.2	JunAug
	120	55.2	MayJul	32.0	AprJun	30.6	JunAug	30.9	JunAug	21.6	AprJun	31.5	JunAug	29.8	AprJun	28.1	JulSep
	121	38.5	MayJul	15.0	AprJun	7.7	MarMay	8.9	AprJun	9.5	MarMay	11.6	AprJun	--	--	--	--
	125	--	--	--	--	--	MarMay	19.6	AprJun	25.3	MayJul	44.3	JunAug	27.9	AprJun	25.5	MarMay
	126	--	--	33.0	AprJun	32.5	AprJun	22.7	AprJun	29.2	AprJun	31.4	MayJul	26.3	AprJun	27.0	MarMay
	127	--	MarMay	21.8	AprJun	31.9	JulSep	33.0	JunAug	20.6	AprJun	25.0	AprJun	21.8	AprJun	21.6	JunAug
	129/131	62.9	MayJul	28.5	AprJun	26.3	AugOct	35.9	JunAug	21.7	AprJun	31.5	JunAug	31.9	JunAug	40.3	JunAug
	137	40.8	MayJul	20.7	AprJun	17.7	AprJun	8.1	MarMay	13.5	AprJun	17.7	AprJun	21.3	MarMay	19.0	MarMay
	139	--	--	--	--	--	--	--	--	--	--	--	--	--	--	62.2	JulSep
	142	--	--	--	--	--	--	--	--	--	--	--	--	19.6	AprJun	22.0	MarMay
	152	--	--	32.2	AprJun	51.8	JulSep	23.8	JulSep	28.5	AprJun	33.6	JunAug	19.2	AprJun	36.7	JunAug
	153	21.4	JulSep	20.1	JunAug	50.4	JunAug	21.4	JunAug	24.1	MayJul	32.4	JunAug	23.2	AprJun	39.5	JunAug
	571	--	--	--	--	--	--	--	--	--	--	--	--	29.4	JulSep	33.5	JunAug
Southern Periphery	150	--	MarMay	13.7	AugOct	20.0	JulSep	16.6	JunAug	10.8	AprJun	16.1	JulSep	15.3	MarMay	20.4	JunAug
	151	--	--	19.9	AprJun	27.1	AugOct	27.0	JunAug	18.5	AprJun	12.3	MarMay	22.9	MarMay	24.3	JunAug
	156	--	--	17.8	MarMay	14.1	AprJun	7.3	MarMay	18.2	MarMay	12.5	MarMay	13.7	MarMay	13.6	AprJun
West	161	--	--	8.8	JulSep	14.8	AprJun	29.9	AprJun	12.5	AprJun	12.9	AprJun	24.0	AprJun	11.3	AprJun
	162	--	--	9.3	JulSep	14.1	AprJun	29.2	AprJun	22.8	AprJun	13.8	MayJul	--	--	--	--
	163	--	--	0.8	AugOct	6.2	JunAug	4.1	MayJul	12.1	MayJul	0.4	MarMay	--	--	--	--
	164	--	--	13.1	JulSep	6.1	JunAug	14.3	MayJul	14.5	MayJul	7.2	MarMay	--	--	--	--
	165	--	--	17.7	AprJun	8.3	MayJul	19.9	MayJul	15.5	AprJun	5.5	MayJul	16.3	MayJul	7.0	JunAug
	167	--	--	10.2	JulSep	12.9	MayJul	22.9	AprJun	12.8	AprJun	18.7	AprJun	24.0	MayJul	--	MarMay
	168	--	--	1.3	AprJun	0.2	MarMay	0.7	AprJun	1.0	AprJun	0.0	MarMay	0.1	JunAug	--	MarMay
	169	--	--	20.1	JulSep	13.4	MayJul	23.2	AprJun	13.8	AprJun	9.8	MayJul	28.2	MayJul	10.6	AprJun
	174	--	--	13.8	JulSep	18.3	MayJul	26.5	AprJun	21.8	AprJun	9.9	AprJun	24.5	MayJul	--	MarMay

Note: All values in ppm-hr.

Source: QST.

Table 3-41. Maximum Annual 3-Month Rolling W126 of Ozone Concentrations by Region/Site

Region	Site	1988		1989		1990		1991		1992		1993		1994		1995	
		Maximum	Period	Maximum	Period	Maximum	Period	Maximum	Period	Maximum	Period	Maximum	Period	Maximum	Period	Maximum	Period
Northeast	103/104	37.6	JunAug	16.6	MayJul	16.1	JunAug	23.8	MayJul	12.7	MayJul	19.2	JunAug	--	--	--	--
	106	37.9	JunAug	14.1	MayJul	21.8	JunAug	33.8	JunAug	18.1	MayJul	25.1	JunAug	22.4	JunAug	24.4	JunAug
	107	38.3	JunAug	16.0	MayJul	17.4	JunAug	23.4	MayJul	11.0	MayJul	20.8	MayJul	18.2	AprJun	19.7	JunAug
	110	30.4	JunAug	16.4	MayJul	12.5	AprJun	23.4	MayJul	14.8	MayJul	12.1	MarMay	14.9	MayJul	14.8	JunAug
	112	--	--	20.5	MayJul	17.0	JunAug	26.1	MayJul	15.9	MayJul	17.8	JunAug	14.1	MayJul	15.7	JunAug
	113	41.7	MayJul	24.8	JunAug	20.8	JunAug	36.3	MayJul	17.2	MayJul	24.1	JunAug	22.2	JunAug	23.3	JunAug
	116	--	--	29.6	JunAug	33.0	JunAug	43.0	JunAug	24.2	JunAug	37.4	JunAug	29.5	JunAug	30.5	JunAug
	117	47.1	JunAug	19.0	JunAug	19.2	JunAug	28.5	JunAug	12.8	MayJul	22.4	MayJul	19.1	MayJul	23.3	JunAug
	119	36.9	JunAug	12.1	AprJun	14.5	JunAug	21.0	JunAug	9.9	AprJun	17.1	JunAug	17.3	AprJun	12.5	JunAug
	128	40.8	JulSep	26.1	JunAug	29.0	JunAug	42.0	JunAug	18.9	JunAug	32.6	JunAug	29.8	JunAug	30.8	JunAug
	144	--	--	27.2	MayJul	29.4	JunAug	38.3	JunAug	24.1	JunAug	32.5	JunAug	29.5	JunAug	34.3	JunAug
	147	--	--	--	--	--	--	--	--	--	--	--	--	20.0	JunAug	20.5	JunAug
	175	--	--	--	--	--	--	--	--	--	--	--	--	14.7	JunAug	20.2	JunAug
Upper Northeast	105	15.9	MayJul	9.9	MayJul	10.3	MayJul	14.1	AprJun	10.7	AprJun	--	MarMay	--	--	--	--
	109	--	--	9.7	MarMay	8.1	AprJun	9.6	AprJun	9.7	AprJun	4.1	MarMay	5.8	AprJun	--	MayJul
	132	--	--	--	--	--	--	--	--	--	--	4.7	JunAug	AugOct	MayJul	6.3	MayJul
	135	--	--	5.8	MarMay	4.6	AprJun	5.0	AprJun	6.6	AprJun	3.9	MarMay	4.2	AprJun	3.6	MayJul
	145	--	--	--	--	--	--	--	--	--	--	--	--	15.0	JunAug	14.1	JunAug
Midwest	114	--	MarMay	27.8	JunAug	27.0	JunAug	34.2	JunAug	18.0	MayJul	25.7	JunAug	24.4	JunAug	27.8	JunAug
	115	15.0	JulSep	22.1	JunAug	19.8	JunAug	29.2	MayJul	15.5	MayJul	9.3	MayJul	15.5	MayJul	16.3	JunAug
	122	51.8	JunAug	27.8	JunAug	27.8	JunAug	35.7	JunAug	16.5	MayJul	21.9	JunAug	27.6	JunAug	25.8	JunAug
	123	--	--	27.3	JunAug	22.2	JunAug	36.8	MayJul	20.8	MayJul	18.0	JunAug	22.7	MayJul	21.5	JunAug
	130	48.5	MayJul	28.0	JunAug	21.3	JunAug	30.3	JunAug	16.7	AprJun	12.7	MayJul	22.1	MayJul	29.2	JunAug
	133	--	MarMay	27.6	MayJul	21.8	JunAug	29.2	JunAug	17.8	MayJul	3.9	JunAug	22.9	MayJul	27.9	JunAug
	136	--	--	--	--	--	--	--	--	--	--	5.5	AugOct	22.1	AprJun	24.2	JunAug
	138	--	--	--	--	--	--	--	--	--	--	--	--	16.2	AprJun	18.9	MayJul
	140	46.6	MayJul	23.1	MayJul	23.8	JunAug	28.8	JunAug	17.3	AprJun	15.3	JunAug	23.6	JunAug	24.9	JunAug
	146	40.6	MayJul	21.2	JunAug	13.2	JunAug	26.2	JunAug	14.6	MayJul	--	MarMay	--	--	--	--
	157	10.1	AugOct	29.6	JunAug	27.0	JunAug	30.4	JunAug	22.0	MayJul	15.4	JunAug	23.5	JunAug	31.2	JunAug
	572	--	--	--	--	--	--	--	--	--	--	--	--	27.2	JunAug	35.9	JunAug
Upper Midwest	124	19.1	JulSep	22.3	MayJul	15.5	JunAug	21.7	MayJul	13.1	MayJul	8.3	JunAug	12.1	MayJul	16.6	JunAug
	134	--	MarMay	9.0	MayJul	5.7	AprJun	8.8	AprJun	10.8	AprJun	5.0	MarMay	7.8	AprJun	13.7	MayJul
	149	24.0	JulSep	18.4	MayJul	10.1	MayJul	18.0	MayJul	14.1	MayJul	7.6	MayJul	13.4	AprJun	15.8	MayJul

Table 3-41. Continued, Page 2 of 2

Region	Site	1988		1989		1990		1991		1992		1993		1994		1995	
		Maximum	Period	Maximum	Period	Maximum	Period	Maximum	Period	Maximum	Period	Maximum	Period	Maximum	Period	Maximum	Period
South Central	101	41.3	JunAug	20.5	MayJul	--	--	--	--	--	--	--	--	--	--	--	--
	102	38.1	MayJul	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	108	33.0	JunAug	18.0	AprJun	18.0	JunAug	19.6	MayJul	15.7	MayJul	25.1	JunAug	22.9	AprJun	14.2	JunAug
	111	--	--	9.3	JulSep	25.2	JunAug	15.1	JunAug	14.8	AprJun	16.8	MayJul	19.4	AprJun	20.1	JunAug
	118	40.9	JulSep	23.6	MayJul	25.6	JunAug	28.8	MayJul	16.9	MayJul	28.1	MayJul	20.4	AprJun	22.1	JunAug
	120	44.0	JunAug	21.6	AprJun	22.1	JunAug	21.1	JunAug	15.0	AprJun	22.0	MayJul	20.5	AprJun	19.3	JulSep
	121	29.6	MayJul	11.5	AprJun	7.1	MarMay	6.9	AprJun	7.5	MarMay	8.7	AprJun	--	--	--	--
	125	--	--	--	--	--	MarMay	14.2	MayJul	17.4	MayJul	31.1	JunAug	20.3	AprJun	16.7	MarMay
	126	--	--	21.6	AprJun	24.1	AprJun	16.1	JunAug	19.1	AprJun	20.4	MayJul	18.4	AprJun	18.8	MarMay
	127	--	MarMay	15.5	AprJun	23.1	JunAug	22.9	JunAug	14.5	AprJun	17.4	AprJun	15.5	AprJun	15.7	JulSep
	129/131	50.9	MayJul	20.8	AprJun	18.6	AugOct	25.1	JunAug	15.8	AprJun	23.1	JunAug	22.7	AprJun	28.7	JunAug
	137	30.6	MayJul	14.0	MarMay	13.8	AprJun	7.8	MarMay	10.8	MarMay	12.2	AprJun	15.0	MarMay	13.8	MarMay
	139	--	--	--	--	--	--	--	--	--	--	--	--	--	--	47.2	JulSep
	142	--	--	--	--	--	--	--	--	--	--	--	--	14.3	AprJun	15.0	MarMay
	152	--	--	22.2	AprJun	38.9	JulSep	17.1	JunAug	20.2	AprJun	24.6	JunAug	14.2	AprJun	26.7	JunAug
	153	17.2	JulSep	15.5	JunAug	39.6	JunAug	16.8	JunAug	17.9	MayJul	25.8	JunAug	16.8	AprJun	30.7	JunAug
	571	--	--	--	--	--	--	--	--	--	--	--	--	20.5	JunAug	25.8	JunAug
Southern Periphery	150	--	MarMay	10.1	AugOct	14.2	JulSep	12.3	JunAug	8.6	AprJun	11.6	JulSep	12.1	AprJun	14.9	JunAug
	151	--	--	14.4	AprJun	19.3	AugOct	19.6	JunAug	13.7	AprJun	10.0	MarMay	16.5	MarMay	17.7	JunAug
	156	--	--	12.9	MarMay	10.3	AprJun	5.7	MarMay	13.9	MarMay	9.9	MarMay	12.0	MarMay	10.2	AprJun
West	161	--	--	9.9	JulSep	13.5	AprJun	19.1	AprJun	11.9	AprJun	12.8	AprJun	17.5	MarMay	12.5	MarMay
	162	--	--	10.5	JulSep	12.7	AprJun	19.4	AprJun	16.2	AprJun	12.3	MayJul	--	--	--	--
	163	--	--	3.1	AugOct	7.8	JulSep	6.9	JunAug	10.2	MayJul	3.7	AprJun	--	--	--	--
	164	--	--	12.0	JulSep	8.7	JunAug	11.9	MayJul	11.9	MayJul	8.3	MarMay	--	--	--	--
	165	--	--	13.2	AprJun	10.0	MayJul	15.3	AprJun	12.8	AprJun	8.3	AprJun	13.3	MayJul	9.3	JunAug
	167	--	--	9.8	JulSep	11.0	AprJun	17.1	AprJun	11.3	AprJun	15.0	AprJun	16.4	MayJul	--	MarMay
	168	--	--	3.9	AprJun	2.3	MarMay	3.2	MarMay	2.7	AprJun	1.8	MarMay	2.6	MarMay	--	MarMay
	169	--	--	16.1	JulSep	12.5	MayJul	17.1	AprJun	12.1	AprJun	10.8	AprJun	19.1	MayJul	11.6	JunAug
	174	--	--	11.8	JulSep	14.4	MayJul	18.9	AprJun	16.1	AprJun	11.1	AprJun	18.4	MayJul	--	MarMay

Note: All values in ppm-hr.

Source: QST.

Table 3-42. 1995 Ozone Concentrations and Measures

Site	Land Use	Annual	SUM06	W126	4th Highest Daily Maximum Value Based on Rolling 8-Hour Averages (All Year)	Highest Hourly Value (All Year)
135 (Ashland, ME)	Remote	34	3.2	3.6	65	80
134 (Perkinstown, WI)	Remote	35	17.3	13.7	75	89
118 (Big Meadows, VA)	Mountainous	46	32.2	22.1	90	107
120 (Horton Station, VA)	Mountainous	45	28.1	19.3	81	99
126 (Cranberry, NC)	Mountainous	46	27.0	18.8	79	96
107 (Parsons, WV)	Complex Terrain	30	26.3	19.7	82	100
106 (PSU, PA)	Rolling	32	31.9	24.4	95	112
108 (Prince Edward, VA)	Rolling	34	18.7*	14.2*	83	101
114 (Deer Creek, OH)	Rolling	34	37.3	27.8	87	116
130 (Bondville, IL)	Rolling	34	37.4	29.2	94	119
116 (Beltsville, MD)	Suburban	29	36.5	30.5	104	166
144 (Washington's Crossing, NJ)	Suburban	34	41.1	34.3	109	146

*Lower than previous years.

Source: QST.

Table 3-43. 1992 Ozone Concentrations and Measures

Site	Land Use	Annual	SUM06	W126	4th Highest Daily Maximum Value Based on Rolling 8-Hour Averages (All Year)	Highest Hourly Value (All Year)
135 (Ashland, ME)	Remote	31	6.5	6.6	79	93
134 (Perkinstown, WI)	Remote	32	15.2	10.8	74	95
118 (Big Meadows, VA)	Mountainous	39	22.9	16.9	81	99
120 (Horton Station, VA)	Mountainous	40	21.6	15.0	76	92
126 (Cranberry, NC)	Mountainous	43	29.2	19.1	78	97
107 (Parsons, WV)	Complex Terrain	27	15.2	11.0	70	89
106 (PSU, PA)	Rolling	30	23.8	18.1	90	104
108 (Prince Edward, VA)	Rolling	31	22.0	15.7	79	123
114 (Deer Creek, OH)	Rolling	29	23.8	18.0	83	98
130 (Bondville, IL)	Rolling	26	21.2	16.7	79	98
116 (Beltsville, MD)	Suburban	24	30.7	24.2	92	118
144 (Washington's Crossing, NJ)	Suburban	26	28.6	24.1	102	139

Source: QST.

Table 3-44. Sampling History: Mountain Acid Deposition Program

Sampling Efforts	Whitetop Mt. Site 302	Whiteface Mt. Site 300	Clingman's Dome Site 303	Catskills Mt. Site 301
Samples 1994	165	284	17	
Samples 1995	573	768	147	30
Samples 1996	211	644	123	
Sampling - 1997	Began May 16	Began June 15	Began May 23	Began June 15
Dry Deposition	Weekly Filter Pack	Continuous Gas Monitoring (ASRC)	Weekly Filter Pack	--
Precipitation Analyses	Collected	--	--	--
Liquid Water Content	5-minute average, hourly average	5-minute average, hourly average	5-minute average, hourly average	--
Continuous Meteorological	5-minute average, hourly average	5-minute average, hourly average	5-minute average, hourly average	Wind Direction Windspeed
Ozone	5-minute average, hourly average	5-minute average, hourly average	Data from NPS	--

Source: QST.

Table 3-45. CASTNet Visibility Sites, October 1993 Through November 1995

Site No.	Site Name	Latitude (°N)	Longitude (°W)	Operational Date
510	Connecticut Hill, NY	42.40	76.65	09/20/93
513	M.K. Goddard, PA	41.43	80.15	09/17/93
518†	Shenandoah National Park, VA	38.52	78.44	10/18/93
528	Arendtsville, PA	39.92	77.31	09/16/93
530	Bondville, IL	40.05	88.37	09/24/93
570	Sikes, LA	32.07	92.46	06/10/93
571	Cadiz, KY	36.78	87.85	09/16/93
572*	Quaker City, OH	39.94	81.34	07/24/93
573	Livonia, IN	38.58	86.26	12/31/88
Discontinued Site				
557	Alhambra, IL	38.87	89.62	03/30/94

*Collocated site.
†Collocated with IMPROVE aerosol sampler.

Source: QST.

Table 3-46. Results of Collocated Aerosol Sampling for 1994

Filter	Parameter	Number of Pairs	Average Value Over the Quarter			
			Mean X	Mean Y	Median AD	Median APD
Nylon	Nitrate ($\mu g/m^3$)	44	1.05	1.05	0.02	2.21
	Sulfate ($\mu g/m^3$)	44	6.28	6.61	0.12	2.61
Quartz	Elemental-C ($\mu g/m^3$)	39	0.76	0.68	0.13	24.00
	Organic-C ($\mu g/m^3$)	39	1.90	1.76	0.31	19.35
Teflo	Fine Mass ($\mu g/m^3$)	42	12.10	13.81	0.52	5.52
	Absorbance ($10^{-8}/m$)	42	558.21	581.02	31.35	5.88
	Al (ng/m^3)	23	60.71	67.77	16.18	24.57
	As (ng/m^3)	19	0.74	0.72	0.13	20.99
	Br (ng/m^3)	42	3.07	3.12	0.19	6.35
	Ca (ng/m^3)	42	17.69	19.38	3.09	18.85
	Cr (ng/m^3)	14	2.31	2.80	0.38	18.41
	Cu (ng/m^3)	39	2.22	2.29	0.20	13.04
	Fe (ng/m^3)	42	30.68	33.39	1.77	7.66
	H (ng/m^3)	42	555.94	536.47	46.70	12.28
	K (ng/m^3)	42	43.19	43.26	3.49	8.87
	Mg (ng/m^3)	1	33.76	26.75	7.01	23.17
	Mn (ng/m^3)	26	6.62	7.82	1.19	21.00
	Na (ng/m^3)	25	148.31	175.18	33.18	28.35
	Ni (ng/m^3)	22	0.75	0.74	0.08	12.57
	Pb (ng/m^3)	42	5.63	5.63	0.47	7.84
	Rb (ng/m^3)	7	0.27	0.19	0.05	22.22
	S (ng/m^3)	42	1578.98	1697.39	91.10	4.30
	Se (ng/m^3)	42	2.20	2.26	0.11	6.86
	Si (ng/m^3)	42	111.49	118.74	7.85	14.88
	Sr (ng/m^3)	14	0.24	0.21	0.04	20.04
	Ti (ng/m^3)	28	11.77	13.63	2.37	27.59
	V (ng/m^3)	10	3.08	4.54	1.33	49.75
	Zn (ng/m^3)	42	13.42	13.69	0.68	6.19
	Zr (ng/m^3)	2	0.45	0.45	0.22	54.35

Note: median AD = median absolute difference.
median APD = median absolute percent difference.
mean X and Y = mean value for primary and collocated sensors, respectively.

Source: QST.

Table 3-47. Mobile Dry Deposition System Measurements

Measurement	Methods
Fluxes:	
Ozone	Eddy Correlation
Sulfur dioxide	Eddy Correlation
Carbon dioxide	Eddy Correlation
Nitric Acid	Gradient
Energy budgets:	
Heat flux	Eddy Correlation
Latent heat flux	Eddy Correlation
Soil heat flux	Heat flux plates
Soil storage	Temperature probes
Net radiation	Net radiometer
Wind speed/direction (10 m)	
Temperature/relative humidity (3 m)	
Solar radiation	
Wetness/precipitation	
Leaf area index	
Vegetation description	
Sonic anemometer-winds	Eddy Correlation
Delta temperature	Gradient fluxes
Mean ozone	Deposition velocities
Mean sulfur dioxide	Deposition velocities
Pressure	
Wind speed/direction (3 m)	

Source: QST.

Table 4-1. Synopsis of CASTNet Measurements (Page 1 of 3)*

		SO_2		SO_4^{2-}		O_3		HNO_3		NO_3^-		Total NO_3	
		Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
Concentrations ($\mu g/m^3$)													
Overall	East	8.26	0.58	5.21	0.26	32.76	0.18	2.05	0.36	1.08	0.84	3.10	0.43
	West	0.68	0.77	0.85	0.28	41.58	0.19	0.50	0.41	0.26	0.53	0.76	0.35
Eastern	UNE	2.16	0.41	2.46	0.23	33.01	0.15	0.87	0.49	0.22	0.18	1.07	0.41
Regional	NE	12.33	0.29	5.75	0.16	31.58	0.16	2.46	0.22	0.78	0.55	3.20	0.28
	UMW	3.88	0.42	3.28	0.24	33.25	0.06	1.36	0.27	1.54	0.41	2.87	0.28
	MW	11.14	0.36	5.72	0.17	30.83	0.17	2.45	0.18	2.41	0.31	4.82	0.13
	SC	6.34	0.43	5.77	0.13	35.60	0.19	2.02	0.34	0.58	0.65	2.57	0.33
	SP	2.59	0.36	4.38	0.14	31.26	0.15	1.34	0.21	0.49	0.25	1.81	0.18
Winter	East	12.86	0.59	3.15	0.25	23.15	0.23	1.63	0.39	1.70	0.86	3.30	0.44
	West	0.86	0.85	0.61	0.36	38.36	0.21	0.36	0.49	0.27	1.31	0.62	0.59
Spring	East	7.43	0.57	4.77	0.25	38.94	0.15	2.20	0.36	1.15	0.90	3.32	0.43
	West	0.56	0.87	0.91	0.20	46.48	0.17	0.44	0.34	0.29	0.42	0.72	0.33
Summer	East	5.38	0.66	8.40	0.34	39.35	0.21	2.55	0.46	0.46	0.87	2.97	0.47
	West	0.54	0.61	1.05	0.40	44.00	0.19	0.71	0.44	0.24	0.39	0.94	0.41
Fall	East	7.64	0.62	4.39	0.30	28.69	0.23	1.77	0.40	1.01	0.80	2.75	0.42
	West	0.77	0.90	0.81	0.35	38.80	0.20	0.47	0.47	0.22	0.49	0.69	0.37
Deposition Velocity (cm/sec)													
Overall	East	0.326	0.12	0.108	0.22	0.175	0.22	1.728	0.24				
	West	0.309	0.10	0.159	0.30	0.125	0.25	2.243	0.26				
Eastern	UNE	0.323	0.13	0.105	0.28	0.174	0.25	1.782	0.26				
Regional	NE	0.336	0.10	0.110	0.19	0.184	0.20	1.811	0.20				
	UMW	0.305	0.09	0.099	0.19	0.147	0.21	1.763	0.23				
	MW	0.310	0.14	0.100	0.20	0.158	0.23	1.503	0.26				
	SC	0.337	0.10	0.115	0.23	0.184	0.20	1.805	0.23				
	SP	0.326	0.07	0.103	0.19	0.190	0.11	1.700	0.16				
Winter	East	0.244	0.09	0.086	0.31	0.062	0.31	1.542	0.27				
	West	0.260	0.13	0.111	0.51	0.071	0.40	1.979	0.39				
Spring	East	0.323	0.14	0.130	0.22	0.165	0.32	1.844	0.24				
	West	0.299	0.12	0.180	0.28	0.110	0.35	2.241	0.23				
Summer	East	0.430	0.14	0.117	0.22	0.316	0.18	1.847	0.25				
	West	0.381	0.17	0.197	0.24	0.211	0.36	2.558	0.21				
Fall	East	0.309	0.16	0.096	0.23	0.158	0.36	1.670	0.26				
	West	0.289	0.11	0.149	0.35	0.100	0.28	2.172	0.31				

Table 4-1. Synopsis of CASTNet Measurements (Page 2 of 3)*

		SO_2		SO_4^{2-}		O_3		HNO_3		NO_3^-		Total NO_3	
		Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
Dry Deposition Flux (kg/ha)													
Overall	East	3.93	0.60	0.60	0.33	44.54	0.28	2.52	0.45	0.07	0.75		
	Wes	0.31	0.90	0.14	0.42	35.80	0.30	0.77	0.44	0.03	0.49		
Eastern	UNE	0.93	0.44	0.28	0.43	33.81	0.15	1.17	0.82	0.02	0.42		
Regional	NE	5.87	0.28	0.67	0.18	47.52	0.25	3.13	0.30	0.06	0.55		
	UMW	1.70	0.38	0.34	0.16	33.53	0.20	1.59	0.24	0.10	0.40		
	MW	5.27	0.39	0.64	0.25	41.20	0.26	2.69	0.31	0.15	0.30		
	SC	3.05	0.44	0.70	0.26	50.05	0.26	2.65	0.47	0.05	0.68		
	SP	1.24	0.34	0.48	0.23	44.31	0.15	1.59	0.33	0.04	0.35		
Winter	East	1.25	0.58	0.07	0.31	2.30	0.42	0.45	0.51	0.02	0.76		
	West	0.10	1.03	0.02	0.55	4.29	0.45	0.12	0.52	0.00	1.15		
Spring	East	0.93	0.48	0.16	0.32	11.70	0.33	0.72	0.44	0.02	0.79		
	West	0.06	1.06	0.04	0.36	8.25	0.36	0.17	0.45	0.01	0.51		
Summer	East	0.91	0.69	0.25	0.40	21.83	0.27	0.83	0.51	0.01	0.84		
	West	0.08	0.56	0.05	0.45	15.69	0.43	0.32	0.45	0.01	0.49		
Fall	East	0.93	0.61	0.11	0.34	7.57	0.32	0.51	0.53	0.02	0.76		
	West	0.09	1.07	0.03	0.51	6.19	0.31	0.18	0.52	0.01	0.46		
Wet Deposition (kg/ha)													
Overall	East			7.51	0.30					3.27	0.27		
	West			1.02	0.38					0.77	0.23		
Eastern	UNE			5.53	0.28					2.73	0.31		
Regional	NE			9.05	0.24					4.12	0.17		
	UMW			5.47	0.29					3.16	0.27		
	MW			8.14	0.22					3.40	0.18		
	SC			7.28	0.24					2.77	0.20		
	SP			4.99	0.23					2.39	0.24		
Winter	East			1.04	0.52					0.59	0.45		
	West			0.21	1.34					0.18	1.17		
Spring	East			2.11	0.38					0.99	0.35		
	West			0.37	0.79					0.27	0.82		
Summer	East			2.70	0.42					1.03	0.35		
	West			0.39	0.46					0.33	0.36		
Fall	East			1.75	0.43					0.77	0.45		
	West			0.25	0.72					0.20	0.71		

Table 4-1. Synopsis of CASTNet Measurements (Page 3 of 3)*

		RSO_2	$RFSO_2$	D/T,S	$RHNO_3$	$RFHNO_3$	D/T,N3
Selected Ratios							
Overall	East	0.704	0.869	0.378	0.651	0.972	0.449
	West	0.544	0.692	0.351	0.656	0.965	0.505
Eastern	UNE	0.568	0.771	0.423	0.794	0.985	0.204
Regional	NE	0.763	0.899	0.155	0.757	0.982	0.447
	UMW	0.640	0.834	0.410	0.465	0.943	0.361
	MW	0.745	0.892	0.270	0.500	0.948	0.449
	SC	0.622	0.819	0.365	0.774	0.983	0.522
	SP	0.470	0.717	0.256	0.729	0.978	0.404
Winter	East	0.860	0.948		0.485	0.951	
	West	0.676	0.847		0.571	0.964	
Spring	East	0.700	0.852		0.653	0.968	
	West	0.480	0.598		0.593	0.946	
Summer	East	0.490	0.785		0.846	0.988	
	West	0.435	0.592		0.743	0.972	
Fall	East	0.723	0.892		0.634	0.969	
	West	0.588	0.740		0.679	0.970	

Note: cm/sec = centimeters per second.
CV = coefficient of variation (100*Standard Deviation/mean).
D/T,N = ratio of dry nitrogen flux from HNO_3 to total dry nitrogen flux from HNO_3 and NO_3.
D/T,S = ratio of total dry sulfur flux to total sulfur flux from dry and wet deposition.
kg/ha = kilograms per hectare.
$RFHNO_3$ = ratio of dry nitrogen flux from HNO_3 to total airborne nitrogen present as HNO_3 and NO_3^-.
$RFSO_2$ = ratio of dry sulfur flux from SO_2 to total dry sulfur flux from SO_2 and SO_4^{2-}.
$RHNO_3$ = ratio of airborne nitrogen present as HNO_3 to total airborne nitrogen present as HNO_3 and NO_3^-.
RSO_2 = $(SO_2/2)/[(SO_2/2)+(SO_4^{2-})/3]$, ratio of airborne sulfur present as SO_2 to total airborne sulfur present as SO_2 and SO_4^{2-}.
$\mu g/m^3$ = micrograms per cubic meter.

*For overall and regional values, a site must have 26 valid weeks; for seasonal values, a site must have 7 valid weeks.

Source: QST.

Table 4-2. Percent Completeness Rates for Concentration Data by Site for 1987 through 1995 (page 1 of 2)

	1987	1988	1989	1990	1991	1992	1993	1994	1995
101	73	98	92	---	---	---	---	---	---
102	83	83	---	---	---	---	---	---	---
103/104	90	98	100	100	100	100	69	---	---
105	83	100	92	100	96	98	23	---	---
106	81	100	94	100	100	98	94	94	96
107	---	94	98	98	96	96	100	98	98
108	15	50	96	100	90	96	100	94	73
109	---	2	90	96	98	96	96	85	92
110	21	87	98	100	100	100	100	88	90
111	---	---	58	98	100	98	94	90	71
112	---	---	94	88	100	100	94	94	71
113	---	90	92	98	100	100	94	94	73
114	---	27	94	100	100	96	94	96	69
115	---	37	87	100	96	100	100	94	56
116	---	13	96	100	100	96	90	96	71
117	4	98	100	100	100	96	100	92	73
118	---	33	92	94	100	94	92	92	90
119	15	96	98	98	100	100	98	92	88
120	58	100	100	100	100	96	100	87	85
121	---	88	100	100	100	100	92	---	---
122	35	94	100	100	100	100	100	96	98
123	---	---	87	100	100	100	81	90	69
124	---	33	98	100	100	100	98	94	71
125	---	---	---	27	100	94	100	100	90
126	---	---	88	100	100	100	100	100	73
127	---	15	98	100	100	100	98	94	73
128	---	50	98	100	100	100	94	100	98
129/131	40	79	98	96	98	98	96	87	73
130	---	71	100	98	92	98	98	94	73
132	---	---	---	---	---	12	87	94	85
133	---	44	96	94	98	98	96	96	88
134	---	27	98	98	98	100	98	98	98
135	---	2	94	100	100	96	98	98	67
136	---	---	---	---	---	---	37	98	73
137	15	79	98	100	98	100	96	92	96

Table 4-2. Percent Completeness Rates for Concentration Data by Site for 1987 through 1995 (page 2 of 2)

	1987	1988	1989	1990	1991	1992	1993	1994	1995
138	---	---	---	---	---	---	---	96	65
139	---	---	---	---	---	---	---	---	23
140	40	98	98	100	100	100	100	94	92
142	---	---	---	---	---	---	---	94	92
144	---	2	96	98	98	98	94	94	90
145	---	---	---	---	---	---	---	60	71
146	46	98	98	96	100	96	23	---	---
147	---	---	---	---	---	---	---	92	90
149	---	21	96	100	100	100	100	96	90
150	---	23	85	100	100	100	100	98	73
151	---	2	96	96	96	67	98	83	71
152	---	2	87	100	100	98	100	96	73
153	---	44	73	100	100	100	98	81	88
156	---	---	88	92	98	100	96	96	98
157	---	46	96	100	100	98	100	96	88
161	---	---	63	100	100	100	98	98	98
162	---	---	67	98	96	100	71	---	---
163	---	---	58	100	100	96	73	---	---
164	---	---	58	98	98	96	67	---	---
165	---	---	98	98	90	100	96	98	79
167	---	---	65	100	98	98	100	96	87
168	---	2	92	100	96	100	98	98	96
169	---	---	63	96	100	92	100	92	88
174	---	---	44	100	100	98	100	92	90
175	---	---	---	---	---	---	---	58	92
181	---	---	---	---	---	---	---	2	98
571	---	---	---	---	---	---	23	94	90
572	---	---	---	----	---	---	23	94	90

Source: QST.

Table 4-3. Percent Completeness Rates by Season for 1987 through 1995 for Sites Used in Deposition Velocity and Flux Statistics (Page 1 of 2)

Region/ Site	1987				1988				1989				1990				1991				1992				1993				1994				1995			
	W	SP	SU	F	W	SP	SU	F	W	SP	SU	F	W	SP	SU	F	W	SP	SU	F	W	SP	SU	F	W	SP	SU	F	W	SP	SU	F	W	SP	SU	F
Northeast																																				
103/104	M	92	85	77	92	100	85	100	100	100	100	100	92	85	100	100	100	92	92	100	100	77	77	92	100	92	100	M	--	--	--	--	--	--	--	--
106	M	70	77	92	70	M	M	100	100	100	92	100	100	100	77	70	100	100	100	92	100	M	M	100	62	M	100	100	85	M	M	100	100	92	M	M
107	--	--	--	--	M	70	100	100	62	92	100	100	100	77	77	100	100	100	100	100	100	85	100	62	62	100	100	100	85	100	M	M	92	85	100	77
110	--	--	--	--	92	85	77	100	92	100	100	85	100	100	100	92	100	100	100	100	100	100	100	100	100	77	100	92	92	100	92	100	85	77	100	M
112	--	--	--	--	--	--	--	--	M	100	M	M	70	100	100	100	100	92	70	100	100	85	100	100	100	100	77	85	92	100	100	100	92	100	100	M
113	--	--	--	--	M	70	M	M	M	92	92	100	70	62	92	100	85	M	100	100	92	100	100	100	100	85	M	100	92	92	100	85	100	100	100	M
116	--	--	--	--	--	--	--	--	70	100	100	100	100	100	M	70	100	92	92	100	77	100	100	100	85	85	100	100	92	100	100	100	92	100	85	M
117	--	--	--	--	62	100	100	M	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	77	100	100	92	100	100	100	100	100	92	M
119	--	--	--	--	62	62	85	92	100	100	M	M	100	100	92	100	100	100	100	100	M	62	92	100	92	92	100	92	77	100	100	92	92	92	92	M
128	--	--	--	--	M	M	70	100	100	92	100	100	85	M	100	100	92	100	100	100	100	M	77	100	100	92	77	92	77	100	100	100	100	100	100	77
144	--	--	--	--	--	--	--	--	M	85	92	100	100	70	62	62	100	100	100	100	100	77	100	100	100	92	100	92	62	100	77	70	100	100	85	M
147	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	M	100	92	100	62	100	85	M
175	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	M	M	100	100	100	92	85	100
Upper Northeast																																				
105	M	M	70	100	85	85	100	M	100	100	92	92	92	100	85	100	100	100	100	100	92	100	100	92	100	M	M	M	--	--	--	--	--	--	--	--
109	--	--	--	--	--	--	--	--	M	100	92	100	M	M	62	100	M	85	100	100	85	85	100	100	92	92	100	100	77	M	85	92	85	100	92	92
132	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	M	85	85	92	85	100	70	100	92	100	92	M
135	--	--	--	--	--	--	--	--	70	92	100	100	100	100	100	100	92	92	100	100	100	100	92	100	92	100	62	92	92	100	100	100	92	100	92	M
145	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	M	62	92	100	100	100	100	M
Midwest																																				
114	--	--	--	--	--	--	--	--	M	92	85	100	100	100	62	92	92	85	92	M	85	100	100	100	100	100	100	92	85	100	100	100	100	92	100	M
115	--	--	--	--	M	M	M	100	100	100	100	100	100	100	62	62	100	92	100	100	77	M	85	100	100	62	62	100	85	100	92	92	92	92	M	M
122	--	--	--	--	100	100	M	M	77	100	100	85	100	92	100	92	M	70	100	100	100	100	77	92	100	100	100	100	85	100	92	100	100	92	100	100
123	--	--	--	--	--	--	--	--	M	100	M	62	100	100	100	100	100	M	62	100	100	100	92	100	70	100	100	92	92	100	100	85	92	M	100	100
130	--	--	--	--	M	M	92	100	100	100	100	92	92	100	100	100	100	92	100	77	77	100	92	100	100	100	92	85	M	77	100	77	92	92	92	M
133	--	--	--	--	M	M	M	70	100	70	85	100	92	100	92	85	100	100	100	100	100	100	92	100	100	100	100	100	85	100	100	100	100	100	77	M
136	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	M	M	M	100	92	100	100	100	92	92	100	M
140	M	M	M	62	100	100	100	100	100	100	92	85	100	100	100	100	85	100	M	77	100	100	100	100	100	100	100	77	85	100	85	92	77	92	100	85
146	M	M	M	92	100	100	100	100	100	M	70	M	70	85	70	100	100	92	100	77	85	100	100	77	92	M	M	M	--	--	--	--	--	--	--	--
157	--	--	--	--	M	M	70	92	M	85	100	85	100	100	100	M	77	100	100	92	100	100	100	92	100	100	92	100	92	100	100	100	92	100	92	M
181	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	77	100	100	100
572	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	M	62	92	100	100	100	85	M
Upper Midwest																																				
124	--	--	--	--	M	M	M	92	92	100	100	100	100	85	100	100	92	77	M	M	92	62	100	100	100	85	100	100	92	100	100	100	100	92	92	M
134	--	--	--	--	--	--	--	--	M	100	100	85	100	100	100	100	100	M	62	100	M	62	100	85	100	100	100	100	70	100	100	100	100	100	85	100
149	--	--	--	--	M	M	M	92	100	100	100	100	100	100	100	85	M	M	M	70	92	100	100	100	92	100	100	100	77	100	100	100	100	77	100	M

Table 4-3. Percent Completeness Rates by Season for 1987 through 1995 for Sites Used in Deposition Velocity and Flux Statistics (page 2 of 2)

Region/ Site	1987				1988				1989				1990				1991				1992				1993				1994				1995			
	W	SP	SU	F	W	SP	SU	F	W	SP	SU	F	W	SP	SU	F	W	SP	SU	F	W	SP	SU	F	W	SP	SU	F	W	SP	SU	F	W	SP	SU	F
South Central																																				
101	M	62	92	85	70	100	100	77	92	100	77	M	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
102	M	M	70	85	100	100	85	M	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
108	--	--	--	--	62	M	M	77	100	77	100	85	100	70	92	77	100	77	M	M	100	100	70	92	100	100	100	100	85	M	92	100	100	100	100	M
111	--	--	--	--	--	--	--	--	M	M	70	100	70	92	M	92	M	M	M	62	100	100	77	100	100	85	100	100	85	100	100	92	85	92	100	M
118	--	--	--	--	M	M	M	92	70	70	92	85	92	100	77	M	85	77	92	100	100	100	100	85	77	92	85	100	92	85	85	M	92	100	92	92
120	M	M	62	100	92	77	M	100	100	92	100	72	100	100	100	100	85	92	100	100	85	92	100	100	100	100	100	100	85	92	92	100	85	100	92	M
121	--	--	--	--	M	70	100	92	100	100	100	100	100	100	100	100	100	100	100	100	100	77	92	100	92	92	85	100	--	--	--	--	--	--	--	--
125	--	--	--	--	--	--	--	--	--	--	--	--	M	M	M	70	100	100	100	100	100	100	70	M	100	100	100	85	92	100	100	92	100	100	100	M
126	--	--	--	--	--	--	--	--	M	M	M	85	92	92	M	92	92	100	72	M	M	92	70	85	100	77	100	100	77	100	92	100	M	92	100	M
127	--	--	--	--	--	--	--	--	92	100	92	M	100	100	100	100	100	100	100	M	100	100	100	100	100	100	100	100	85	92	M	100	100	100	77	M
129/131	--	--	--	--	100	M	92	85	100	77	92	100	100	100	M	M	M	M	M	M	100	62	M	100	92	92	85	100	77	92	100	100	70	92	92	M
137	--	--	--	--	62	77	62	92	M	M	M	100	92	100	100	85	100	100	100	100	85	100	70	100	100	92	100	100	92	100	100	M	M	100	85	M
139	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	M	M	70	M
142	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	M	100	62	100	77	92	62	M
152	--	--	--	--	--	--	--	--	62	100	M	100	100	100	100	100	100	M	M	85	M	100	M	100	100	100	100	100	85	92	100	92	100	100	92	M
153	--	--	--	--	--	--	--	--	--	--	--	--	92	85	100	100	70	77	77	92	100	100	100	100	92	100	100	100	77	77	M	100	100	M	77	M
571	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	M	70	100	100	100	100	85	M
Southern Periphery																																				
150	--	--	--	--	M	M	M	70	100	100	77	100	100	100	100	100	100	92	100	M	100	92	92	100	100	100	100	100	85	100	100	100	100	100	100	M
151	--	--	--	--	--	--	--	--	70	85	85	100	92	M	92	100	92	92	85	M	85	100	100	100	M	85	100	92	70	100	100	92	100	100	100	M
156	--	--	--	--	--	--	--	--	62	85	85	77	62	92	70	77	77	92	100	100	92	100	77	100	100	M	70	100	M	100	100	100	100	100	100	100
West																																				
161	--	--	--	--	--	--	--	--	M	M	70	85	100	100	100	92	100	M	70	70	70	100	100	100	92	100	100	100	M	M	92	100	100	100	M	100
162	--	--	--	--	--	--	--	--	M	M	70	100	92	100	92	100	92	100	92	92	100	100	100	100	92	100	100	M	--	--	--	--	--	--	--	--
163	--	--	--	--	--	--	--	--	M	M	70	100	85	100	100	100	100	100	100	100	100	85	100	100	100	70	92	M	--	--	--	--	--	--	--	
164	--	--	--	--	--	--	--	--	M	M	70	100	100	100	100	100	100	100	100	100	100	100														
165	--	--	--	--	--	--	--	--	M	M	100	100	92	100	100	100	100	70	62	M	92	100	92	100	100	100	70	92	92	100	100	92	100	92	100	M
167	--	--	--	--	--	--	--	--	M	M	70	100	100	100	100	100	85	92	92	100	100	100	100	77	100	100	100	100	92	92	100	100	92	M	M	M
168	--	--	--	--	--	--	--	--	M	M	100	100	M	100	100	70	92	92	100	M	92	100	100	100	100	100	100	100	92	70	85	70	92	M	M	M
169	--	--	--	--	--	--	--	--	M	M	70	100	92	M	M	85	77	92	100	100	100	85	92	92	100	100	100	100	92	92	62	77	M	77	92	85
174	--	--	--	--	--	--	--	--	M	M	M	100	100	100	100	100	100	92	100	100	77	100	100	92	100	100	100	100	92	100	62	100	100	M	M	M

* Number of samples with modeled deposition velocity for the season. A site must have at least 8 non-missing modeled values to be included in a season.

Note: F = Fall. M = Missing (less than 8 samples per season). SP = Spring.
SU = Summer. W = Winter.

Source: QST.

Table 4-4. Completion Rates for CDN Precipitation Concentrations and Depositions, 1989 to 1995

Site No.	1989				1990				1991				1992				1993				1994				1995			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
108	69	100	100	92	77	92	69	100	100	100	100	92	100	92	100	92	85	100	100	100	100	100	100	85	100	100	92	--
110	--	--	--	--	--	--	--	--	--	--	--	8	100	92	100	100	100	92	100	92	--	--	--	--	--	--	--	--
111	--	23	100	92	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	92	100	100	100	92	100	92	--
114	62	100	100	100	92	100	100	77	92	92	100	100	100	100	100	100	92	100	100	92	100	100	100	100	100	100	92	--
115	--	100	92	100	100	100	92	100	100	100	92	100	100	100	100	100	92	100	100	100	92	100	92	100	85	92	92	--
119	62	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	92	100	100	100	100	100	92	--
123	--	100	100	92	100	100	100	100	92	100	100	100	92	92	100	100	92	100	92	100	85	100	100	100	92	100	92	--
124	--	92	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	85	--
125	--	--	--	--	--	--	15	100	100	100	100	92	100	100	100	100	100	100	100	100	100	100	100	100	100	100	92	--
126	8	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	92	100	92	--
128	69	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	85	100	100	100	69
134	38	100	100	100	100	100	100	100	100	100	92	100	100	100	100	100	100	100	100	100	100	100	92	100	85	100	100	92
142	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	92	100	100	100	100	100	92	85
145	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	8	92	--
147	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	92	100	100	100	100	100	85	--
156	31	100	77	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	92	100	92	100	100	92	92	85	70	69
157	38	92	100	92	100	100	100	100	100	100	100	100	100	92	92	100	100	92	100	100	100	100	100	100	92	100	85	--
161	--	--	--	15	92	100	100	100	100	92	100	100	85	100	100	100	100	100	100	100	100	100	100	92	100	100	100	92
162	--	38	100	100	100	100	100	100	100	100	100	100	100	92	100	100	100	100	92	--	--	--	--	--	--	--	--	--
167	--	38	100	100	100	100	100	100	92	100	92	100	100	100	100	100	100	100	100	92	100	92	100	100	92	92	92	85
180	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	69	100	92	92	92	100	100	100	100	100	100	85
228	--	--	--	--	--	--	15	100	100	100	92	100	100	92	100	100	100	31	--	--	--	--	--	--	--	--	--	--
257	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	62	100	100	100	100	100	100	100	92	--

Source: QST.

Table 4-5. Percent Completeness* Rates for Ozone Daily Maxima Data (page 1 of 2)

Region	State	Days+	Site	1987	1988	1989	1990	1991	1992	1993	1994	1995
NE	CT	214	147								93.9	83.6
	MD	214	116			98.6	86.9	89.3	93.9	97.2	99.1	82.7
	NJ	214	144			97.7	97.7	99.5	99.5	98.6	95.8	84.6
	NY	214	103/104	86.9	98.1	97.7	94.4	97.7	97.2	72.9		
			110	7.9	93.0	99.5	99.1	99.5	100.0	93.5	85.0	82.7
			175								4.2	19.2
	PA	214	106	70.6	86.9	98.6	97.7	94.4	98.1	96.7	99.1	95.8
			112			97.2	90.7	98.1	98.6	81.3	97.2	80.4
			113		95.3	98.6	85.5	96.7	97.7	97.7	96.3	83.2
			117		97.7	91.1	97.7	98.6	99.1	99.1	97.7	82.7
			128		56.5	97.7	97.7	97.7	95.3	90.7	97.2	96.3
	WV	214	107		97.7	96.7	98.6	99.1	98.1	96.3	98.1	99.1
			119		94.4	95.8	98.1	96.3	97.2	97.7	96.3	83.2
UNE	NY	214	105	86.9	98.6	87.4	97.7	99.5	97.2			
	ME	214	132							93.9	98.1	77.1
			135			98.6	98.6	96.7	97.7	90.7	99.5	80.8
	NH	214	109			94.4	96.7	98.1	95.3	99.5	97.2	98.6
	VT	214	145								30.8	39.7
MW	IL	214	130		82.7	99.5	96.7	92.5	93.5	93.5	97.7	83.6
			138								90.2	75.7
			146	53.3	98.6	99.1	98.6	92.5	97.7			
			157		30.4	99.1	96.3	98.6	97.7	93.5	97.2	83.2
	IN	183	133			97.8	98.9	98.9	99.5	98.4	96.7	97.8
			140		96.7	99.5	98.9	96.2	96.2	98.9	98.4	94.0
	KY	214	136							29.9	99.1	84.1
	MI	183	115		38.8	94.5	98.4	94.5	91.3	69.9	93.4	91.8
	OH	214	114		2.3	90.2	99.1	97.2	95.8	99.1	98.6	81.8
			122	11.2	92.5	99.1	99.1	98.6	99.1	98.1	96.7	98.1
			123			94.4	83.6	95.3	97.7	98.1	88.3	84.1
UMW	MI	183	124		23.5	97.3	97.8	99.5	95.1	97.8	100.0	97.3
			149		38.8	99.5	98.9	100.0	96.7	97.3	99.5	96.2
	WI	185	134		8.1	95.7	98.4	97.3	97.8	96.8	95.7	95.1

Table 4-5. Percent Completeness* Rates for Ozone Daily Maxima Data (page 2 of 2)

Region	State	Days+	Site	1987	1988	1989	1990	1991	1992	1993	1994	1995
SC	MD	214	139									25.2
	KY	214	121		97.2	99.1	96.7	98.6	95.8	94.4		
			129/131	14.5	78.5	93.0	85.0	91.1	99.5	96.7	97.2	78.5
			571								93.9	82.2
	AL	27	152			89.9	98.9	88.8	93.5	95.7	91.7	76.4
	GA	276	153		51.8	70.3	93.8	97.8	98.6	94.2	97.8	73.9
	NC	214	101	79.0	97.7	94.4						
			125				9.8	98.1	99.1	97.2	95.8	79.4
			126			86.9	92.1	98.1	97.2	98.6	98.6	83.6
			137		78.5	80.8	98.6	97.2	98.6	98.1	98.6	96.3
			142								86.0	84.6
	TN	214	102	85.5	93.9							
			111			50.9	90.2	97.2	96.3	98.6	99.5	80.8
			127		0.0	99.1	97.7	95.3	99.1	89.7	98.6	84.1
	VA	214	108		57.5	95.8	87.9	89.7	91.6	94.4	94.9	83.2
			118		36.4	96.3	87.4	90.7	85.5	91.1	87.4	93.0
			120	55.1	97.2	95.8	99.5	97.7	97.7	98.1	93.9	73.4
SP	AR	276	150		22.1	98.9	98.9	98.2	96.4	93.5	98.2	73.9
	FL	365	156			86.6	84.9	87.4	96.7	87.9	92.6	89.9
	MS	276	151			89.5	97.1	90.6	97.5	97.1	95.3	75.4
WST	AZ	365	167			49.9	94.8	88.8	91.8	89.9	97.3	24.1
			174			44.7	99.5	96.7	92.6	87.4	90.7	15.9
	CO	214	161			39.3	94.4	99.1	93.5	96.3	97.7	97.7
	ID	214	163			23.8	96.7	95.3	92.5	81.3		
	MT	122	168			97.5	99.2	99.2	96.7	99.2	98.4	
	NV	365	164			47.9	79.2	83.6	75.3	44.9		
	UT	153	162			56.9	98.7	90.8	93.5	95.4		
	WY	214	165			93.9	98.1	82.7	96.3	97.7	98.1	58.4
			169			55.1	97.2	76.6	89.3	98.1	99.1	94.9

* Percent Completeness is calculated as: number of valid daily maxima/total ozone season days for a state.
+ Number of days in state's designated ozone season.

Source: QST.

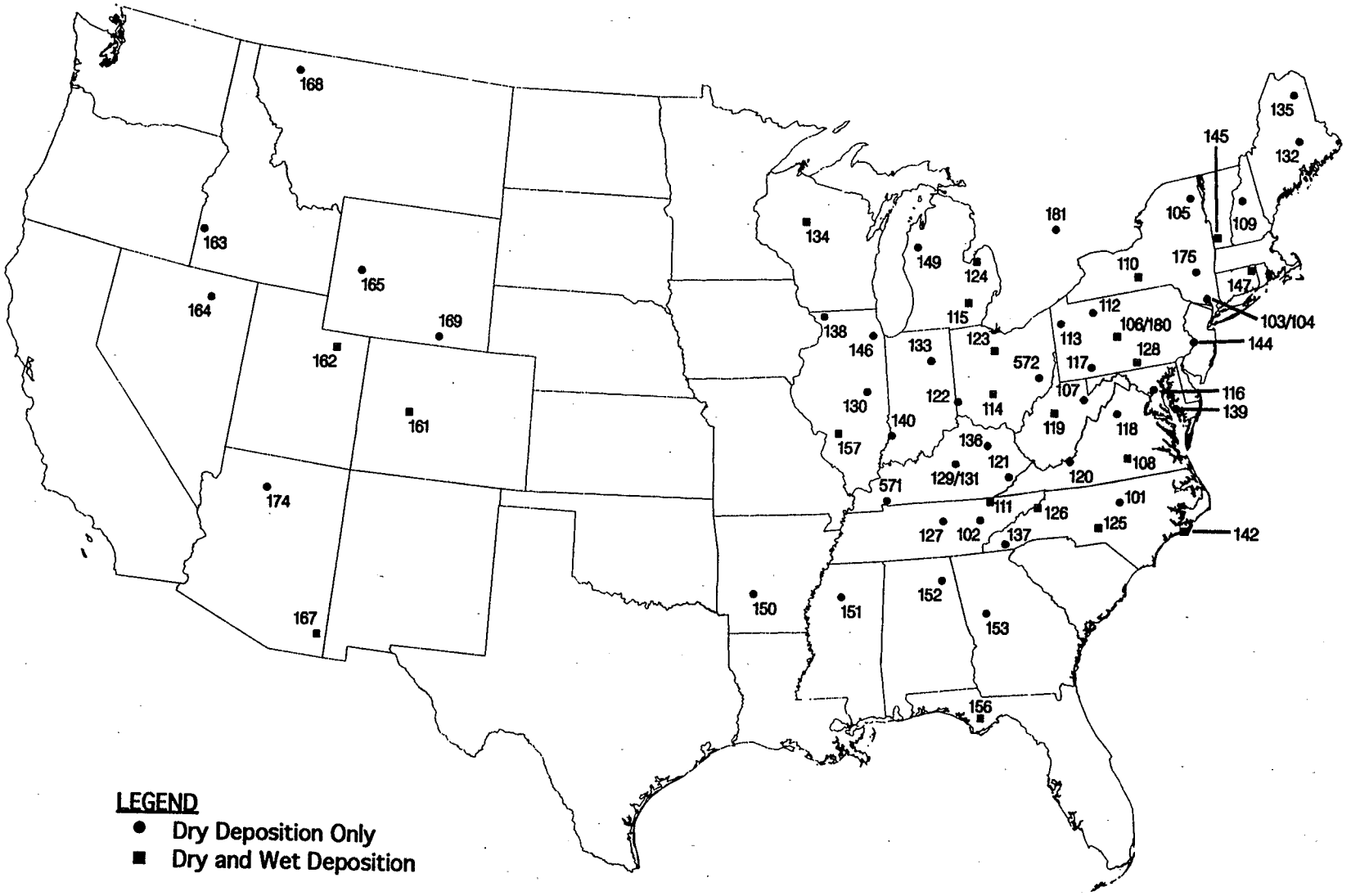


Figure 2-1. CDN monitoring sites

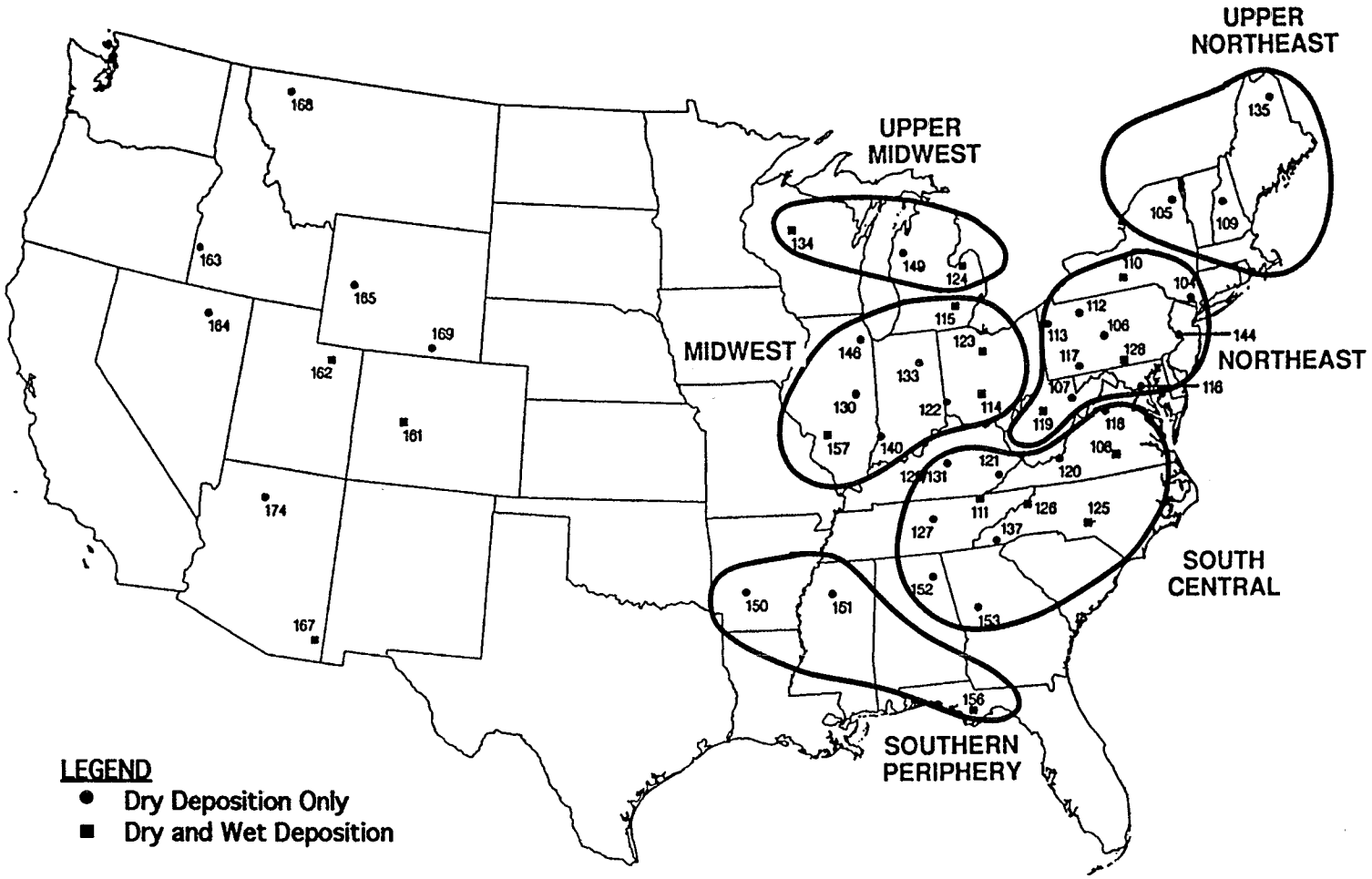


Figure 2-2. Subregions of the CDN for the eastern United States

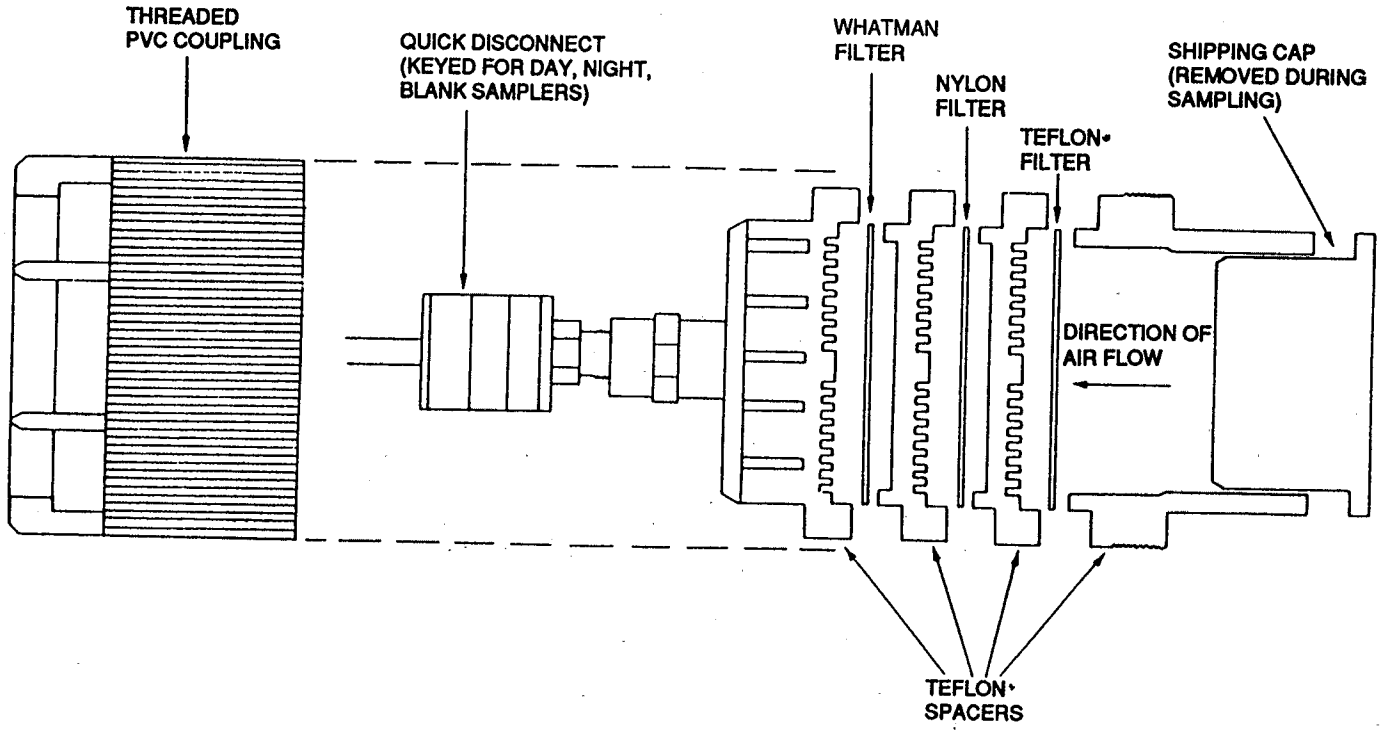
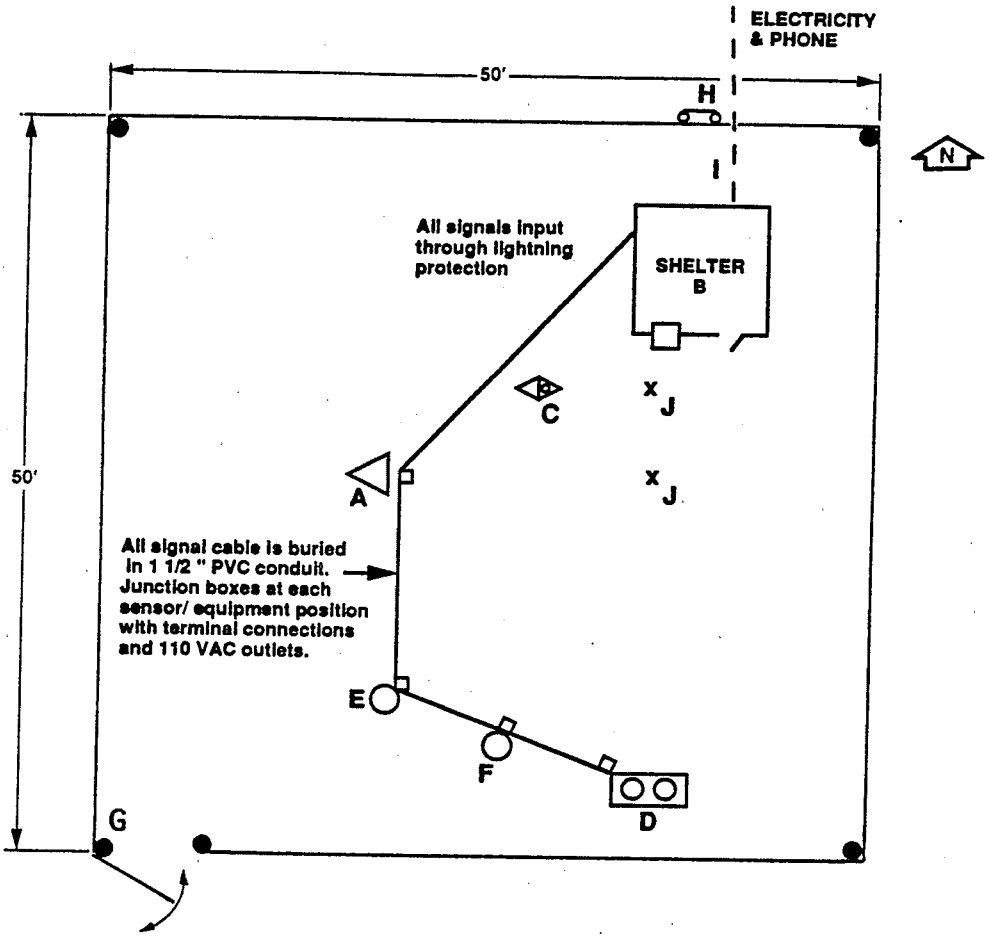


Figure 2-3. Diagram of the filter pack assembly

Figure 2-4. CDN sites with precipitation sampling

CDN SITE CONFIGURATION



KEY

A	METEOROLOGICAL TOWER 10-METER HEIGHT
B	8' x 10' ALUMINUM ENVIRONMENTAL SHELTER, ON SLAB OR PILINGS (4)
C	AIR SAMPLING TOWER, 10-METER HEIGHT
D	WET/DRY COLLECTOR (OPTIONAL)
E	RAIN GAUGE (>5 METERS FROM SHELTER)
F	SOLAR PYRANOMETER (>5 METERS FROM SHELTER)
G	4' OR 6' CHAIN-LINK FENCE WITH GATE (OPTIONAL)
H	STUB POLE, DISCONNECT, AND METER
I	110 VAC/100 AMP AND TELEPHONE LINE UNDERGROUND FOR AT LEAST THE FINAL 50' TO 100'
J	APPROXIMATE POSITION OF TOWER TOP WHEN LOWERED

NOT TO SCALE

Figure 2-5. Typical CDN site configuration

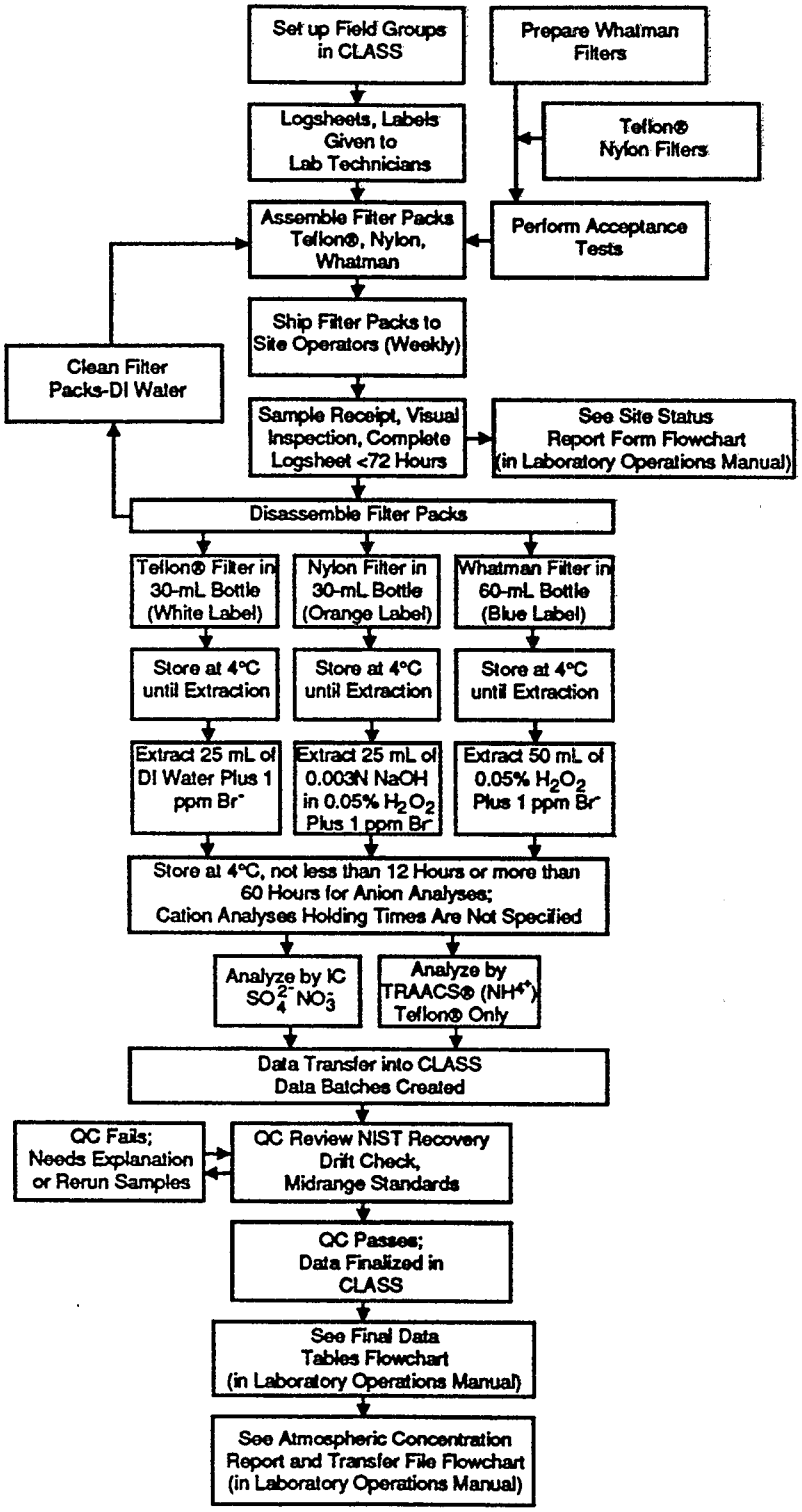


Figure 2-6. Flowchart of laboratory operations for filter pack analyses

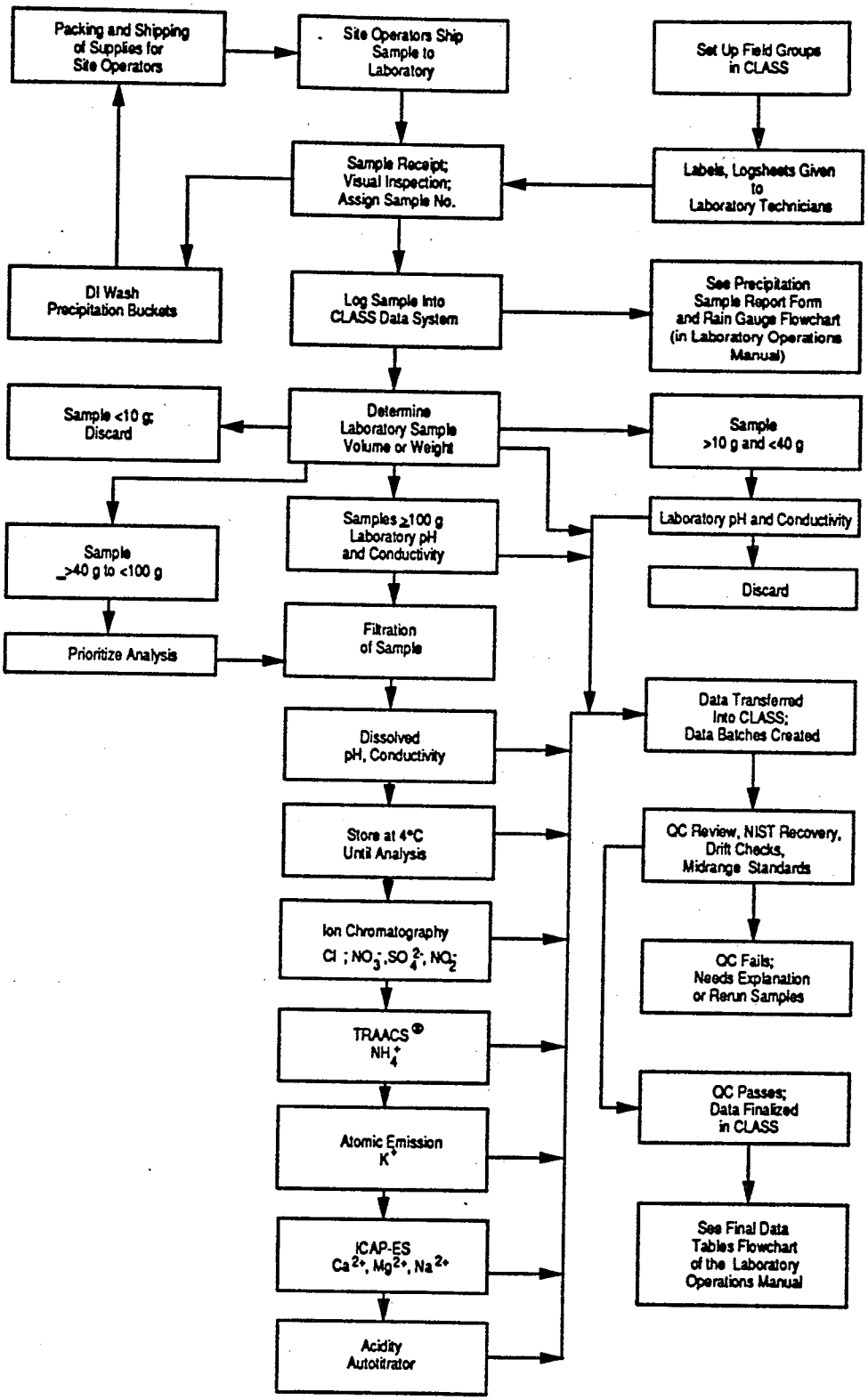


Figure 2-7. Flowchart of laboratory operations for wet deposition analyses

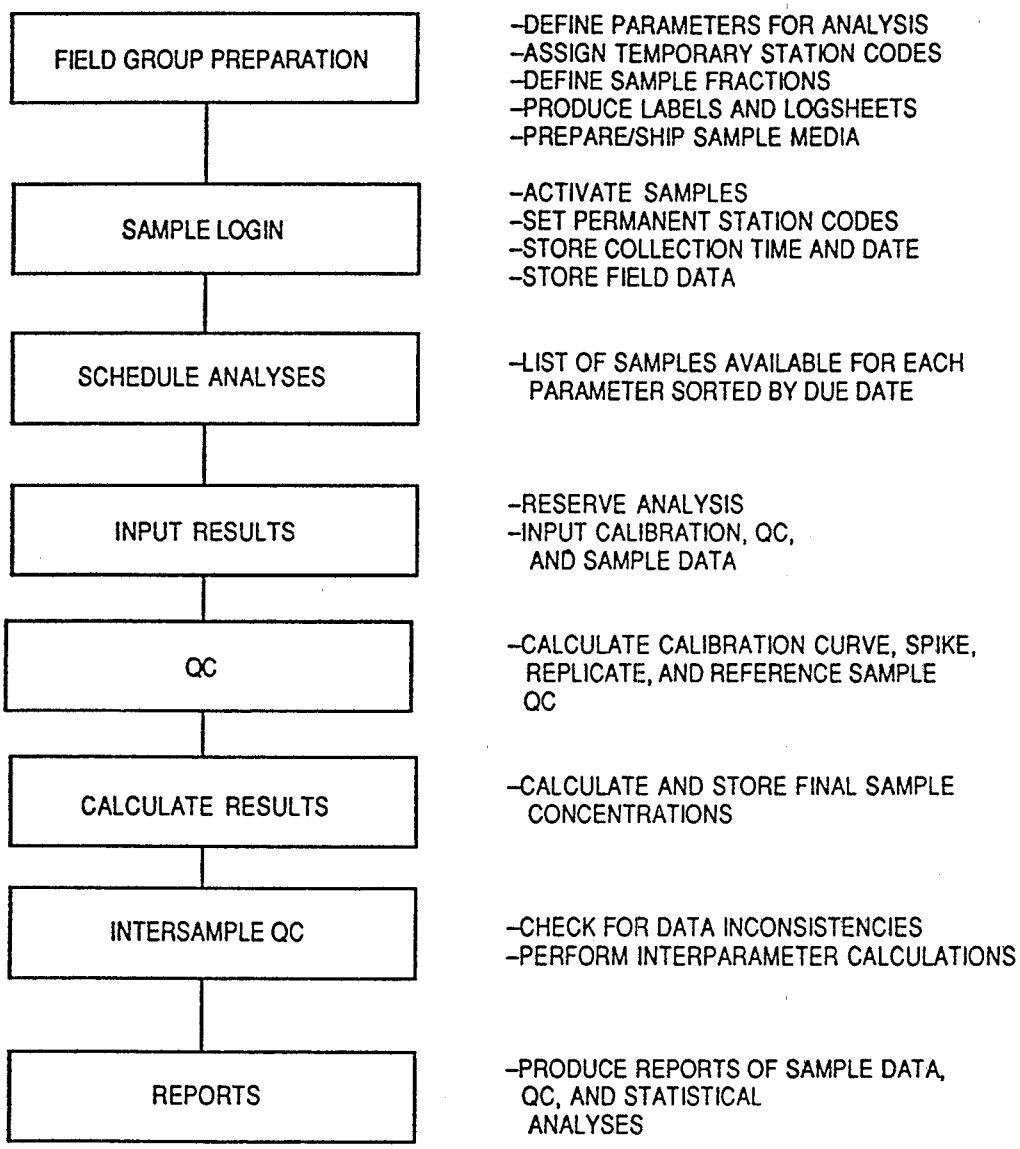


Figure 2-8. Flowchart of the CLASS™ program

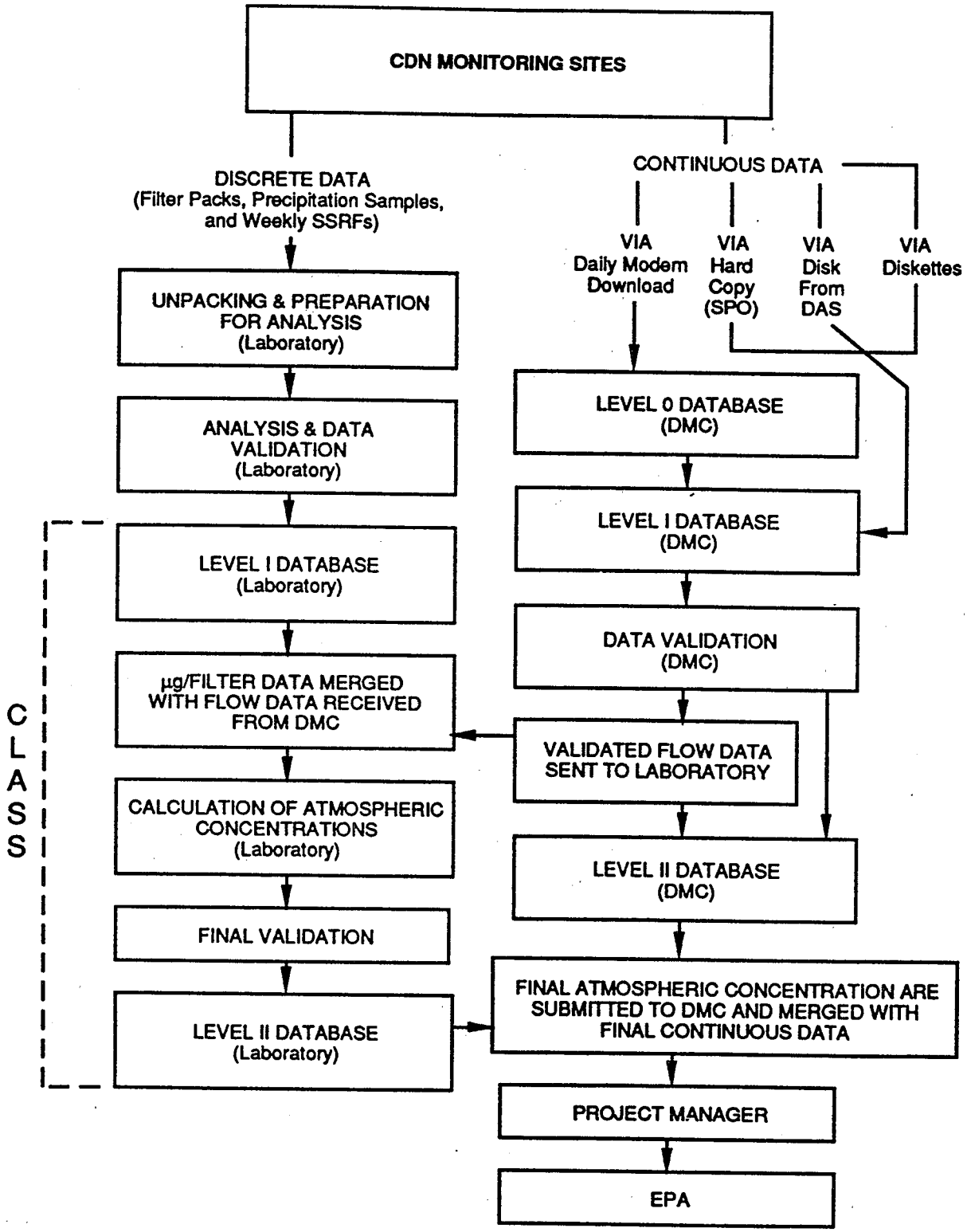


Figure 2-9. Flow of data through CDN

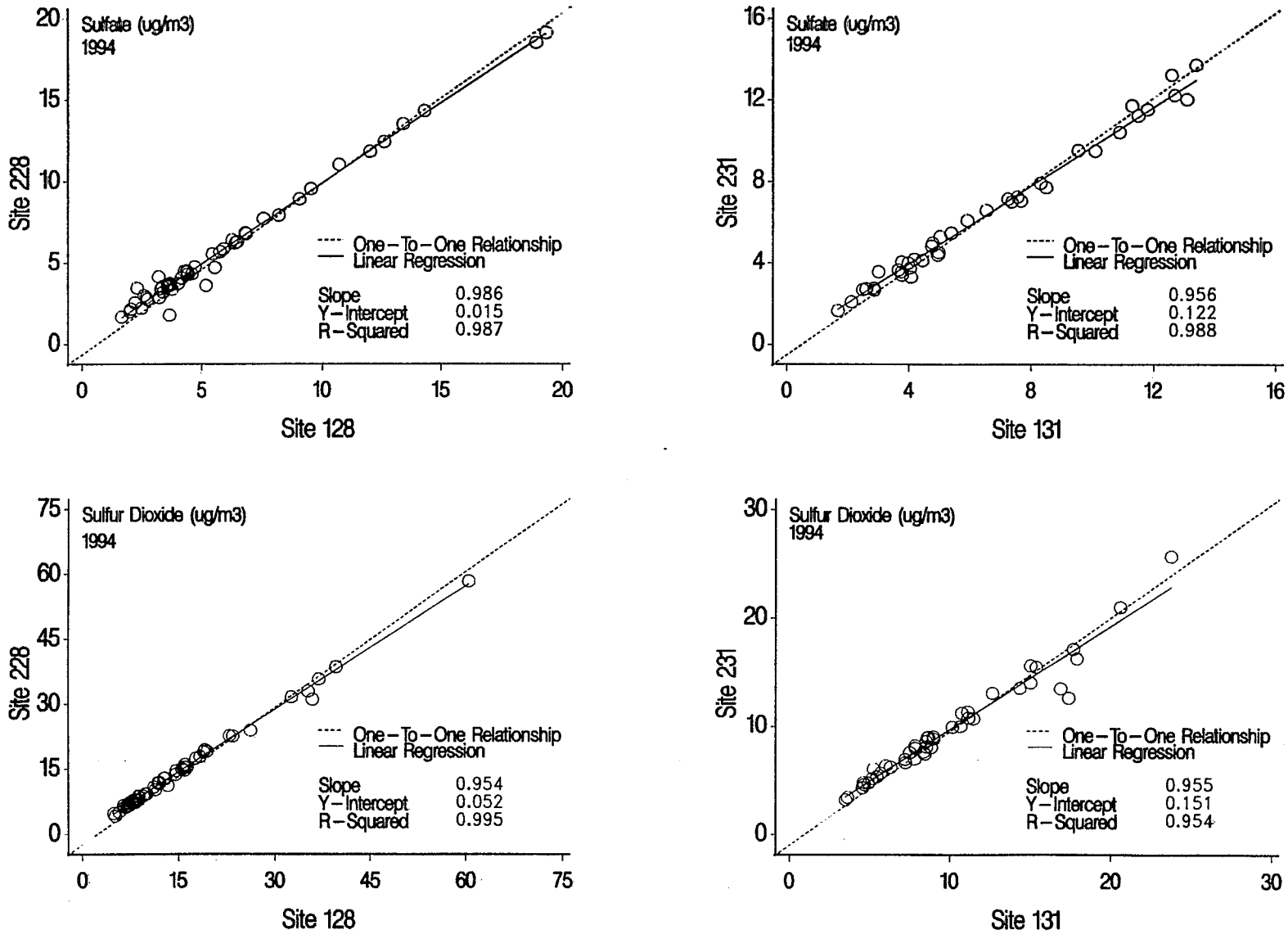


Figure 2-10. Scattergrams of collocated filter pack data for SO_4^{2-} and SO_2 for two eastern sites (128 and 131) for 1994

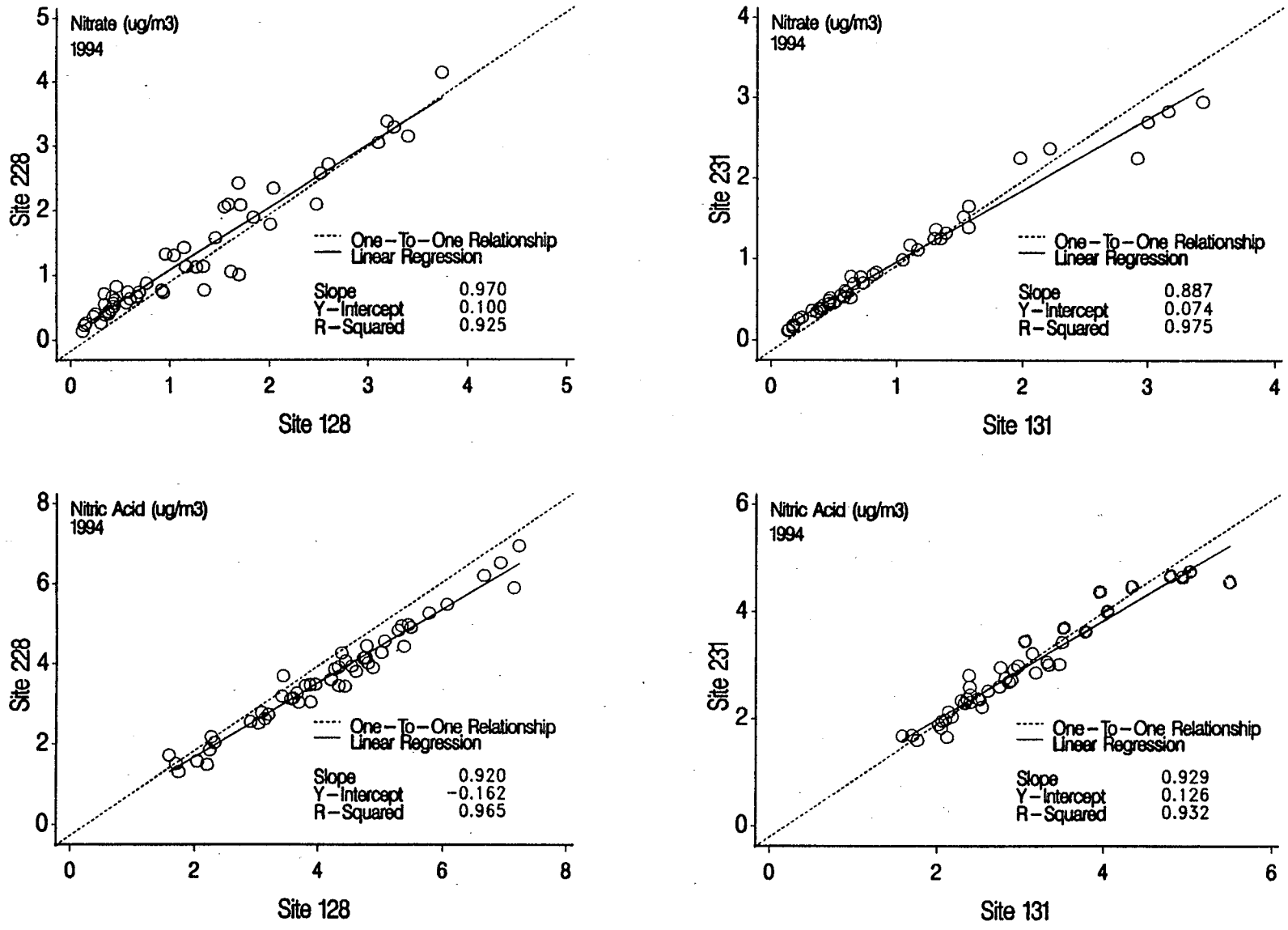


Figure 2-11. Scattergrams of collocated filter pack data for NO_3^- and HNO_3 for two eastern sites (128 and 131) for 1994

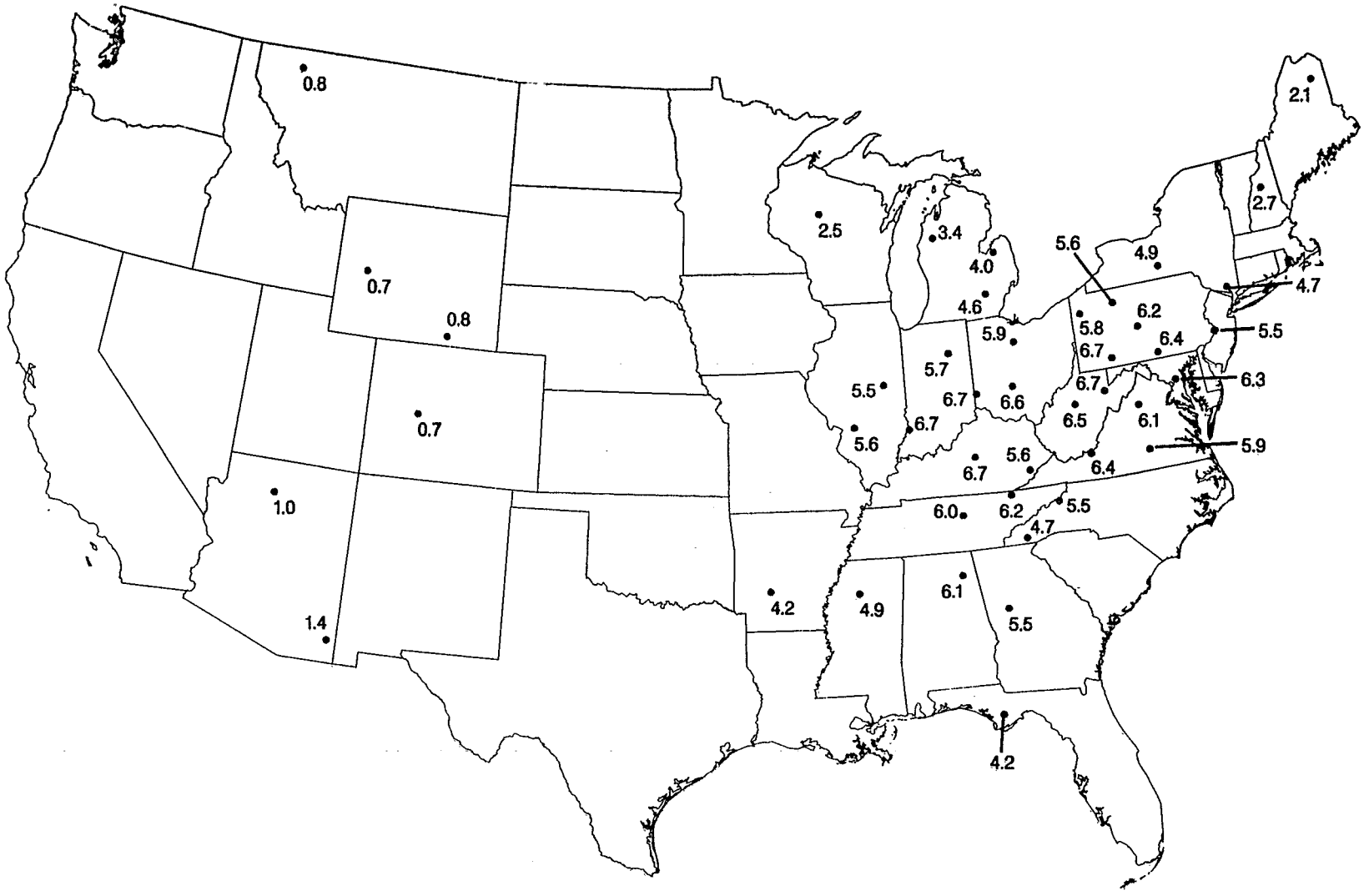


Figure 3-1. Average SO_4^{2-} concentrations ($\mu g/m^3$) from 1989 to 1994

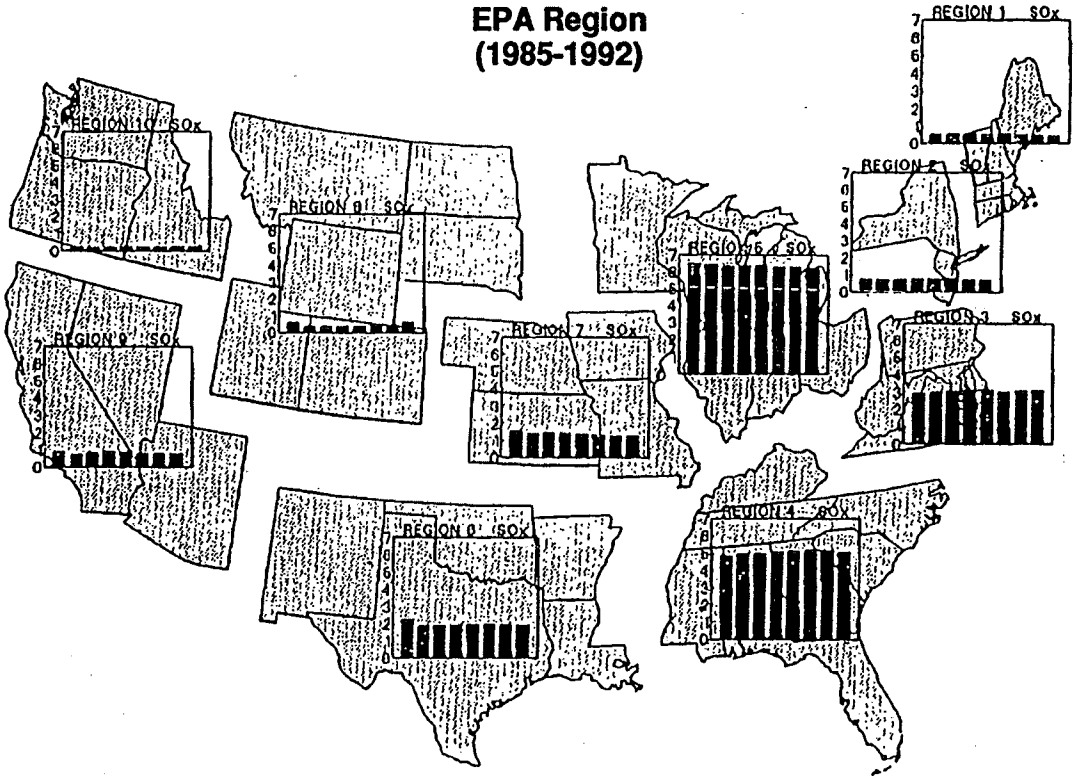


Figure 3-2. SO_x emissions (10^6 metric tons) by EPA Region (1985 to 1992)

SOURCE: EPA, 1996.

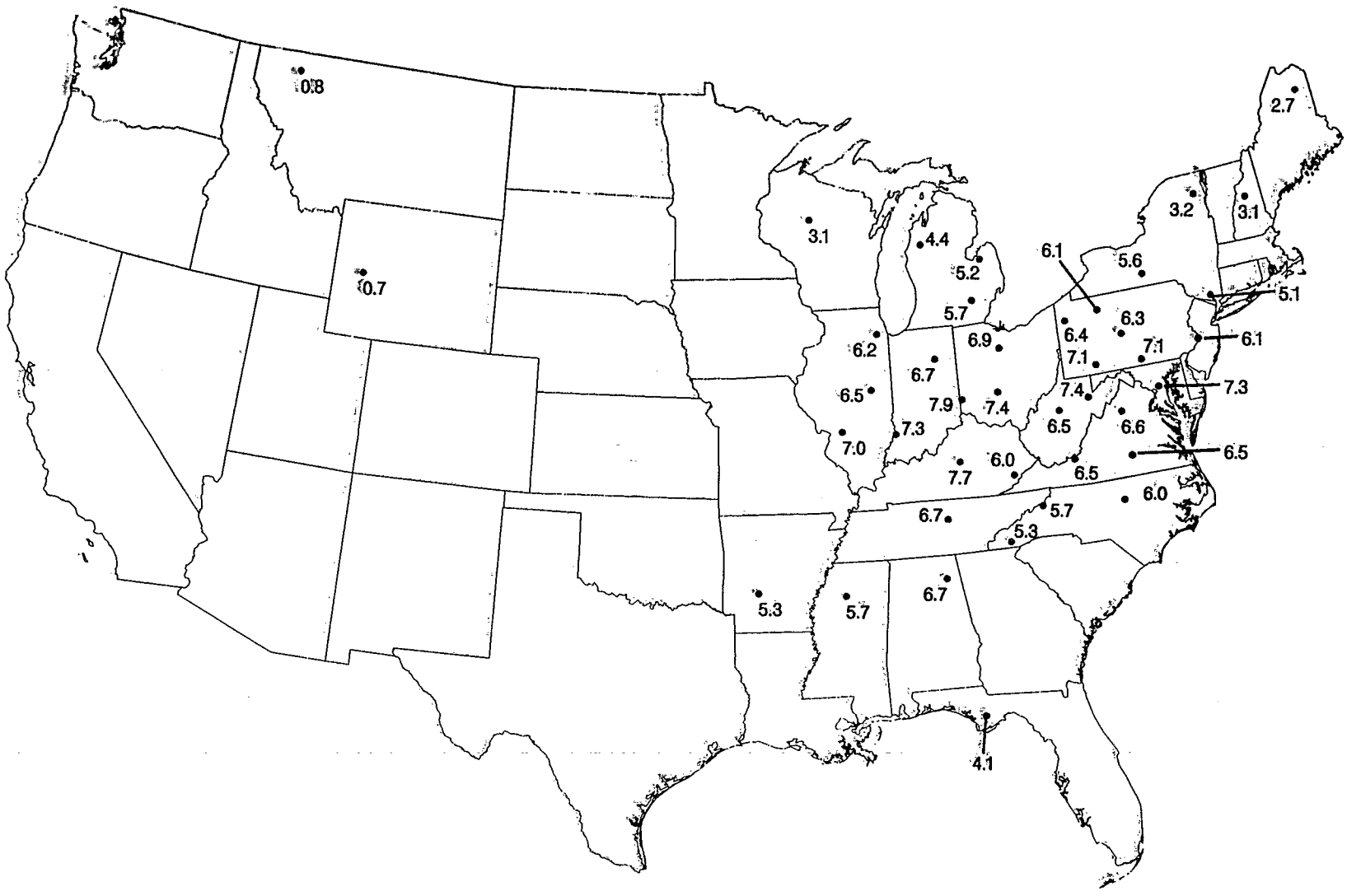


Figure 3-3. Mean annual SO_4^{2-} concentrations ($\mu g/m^3$) for 1989

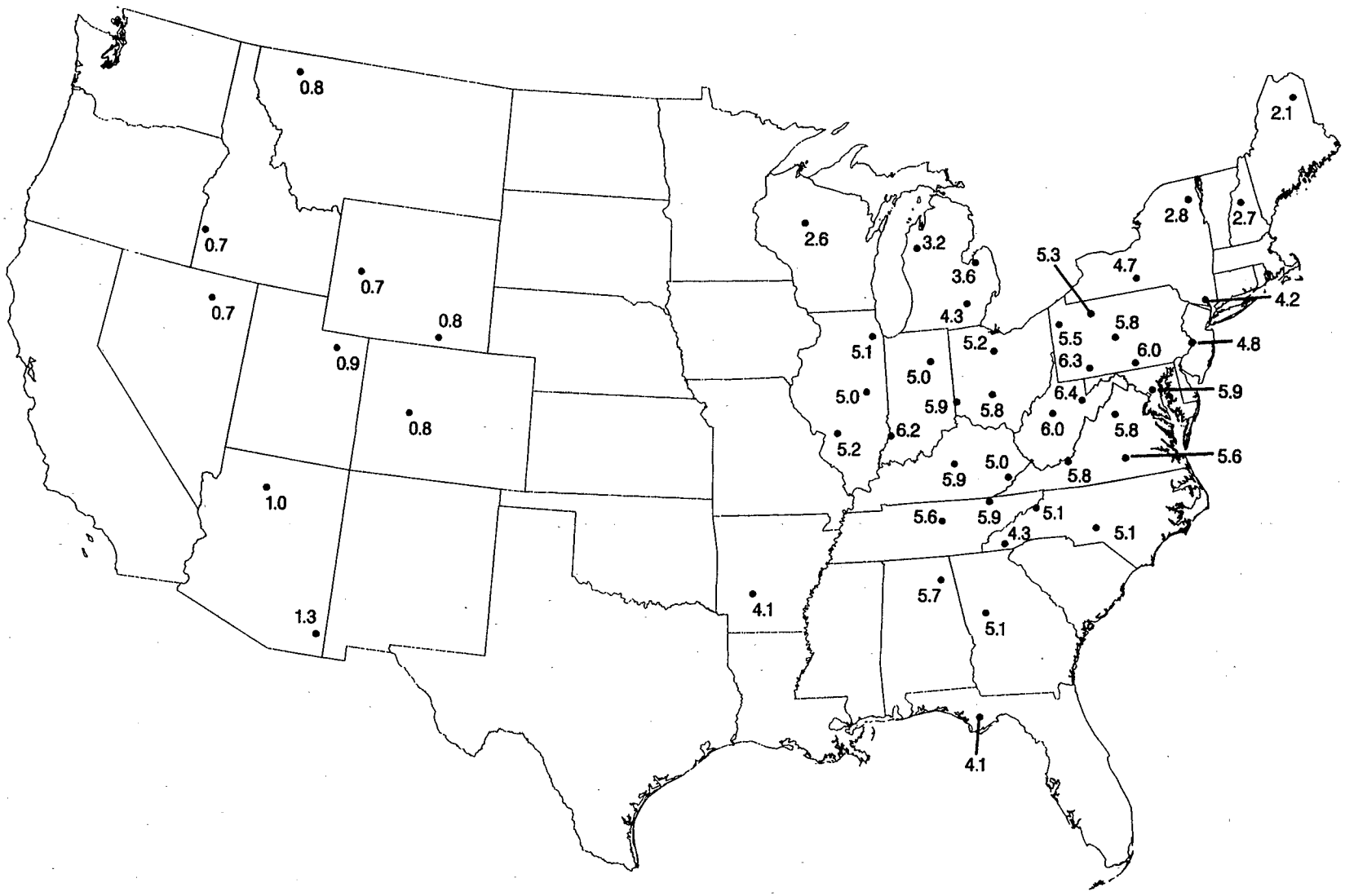


Figure 3-4. Mean annual SO_4^{2-} concentrations ($\mu g/m^3$) for 1992

Figure 3-5. Mean annual SO_4^{2-} concentrations ($\mu g/m^3$) for 1994

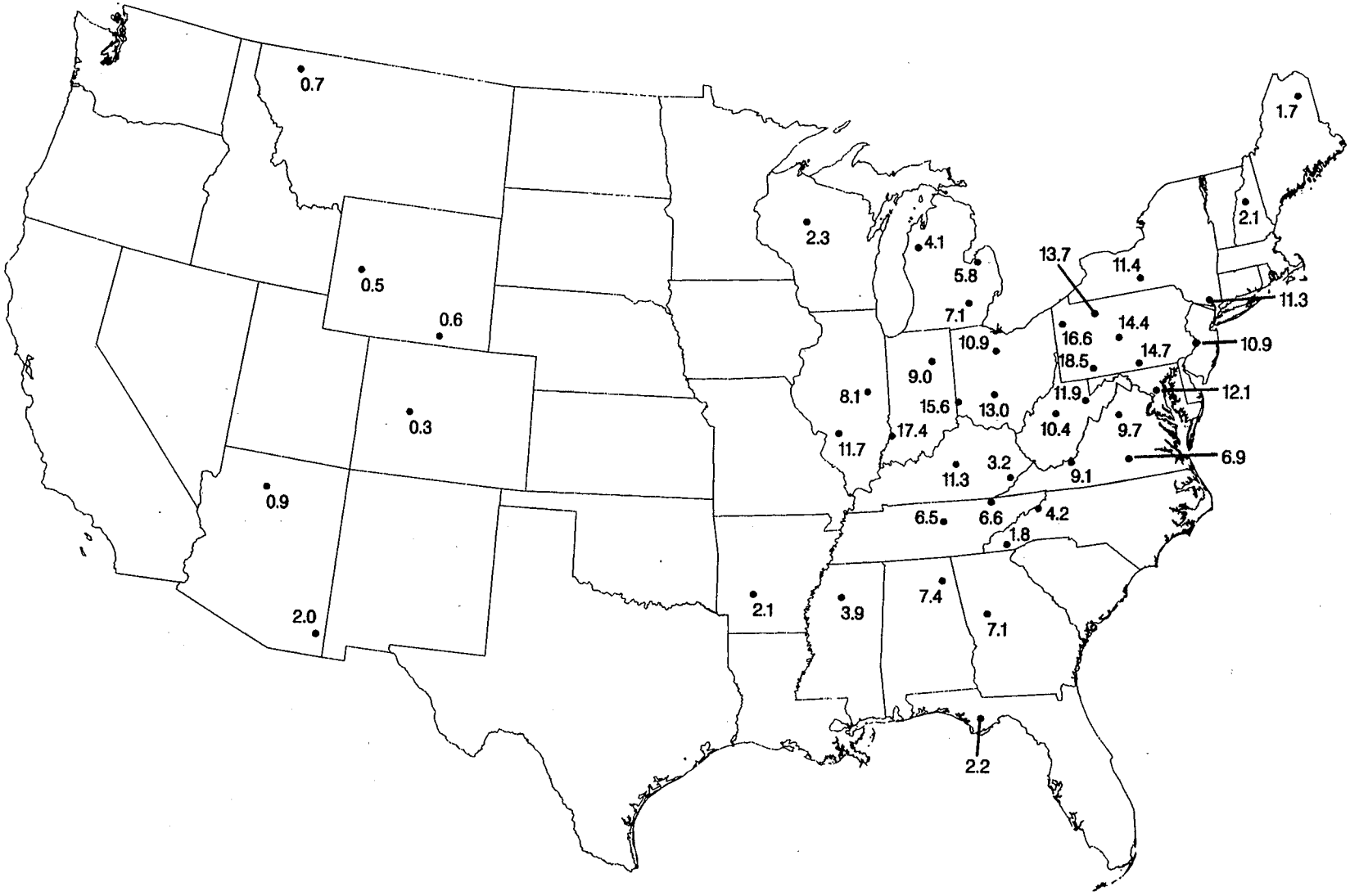


Figure 3-6. Average SO_2 concentrations ($\mu g/m^3$) from 1989 to 1994

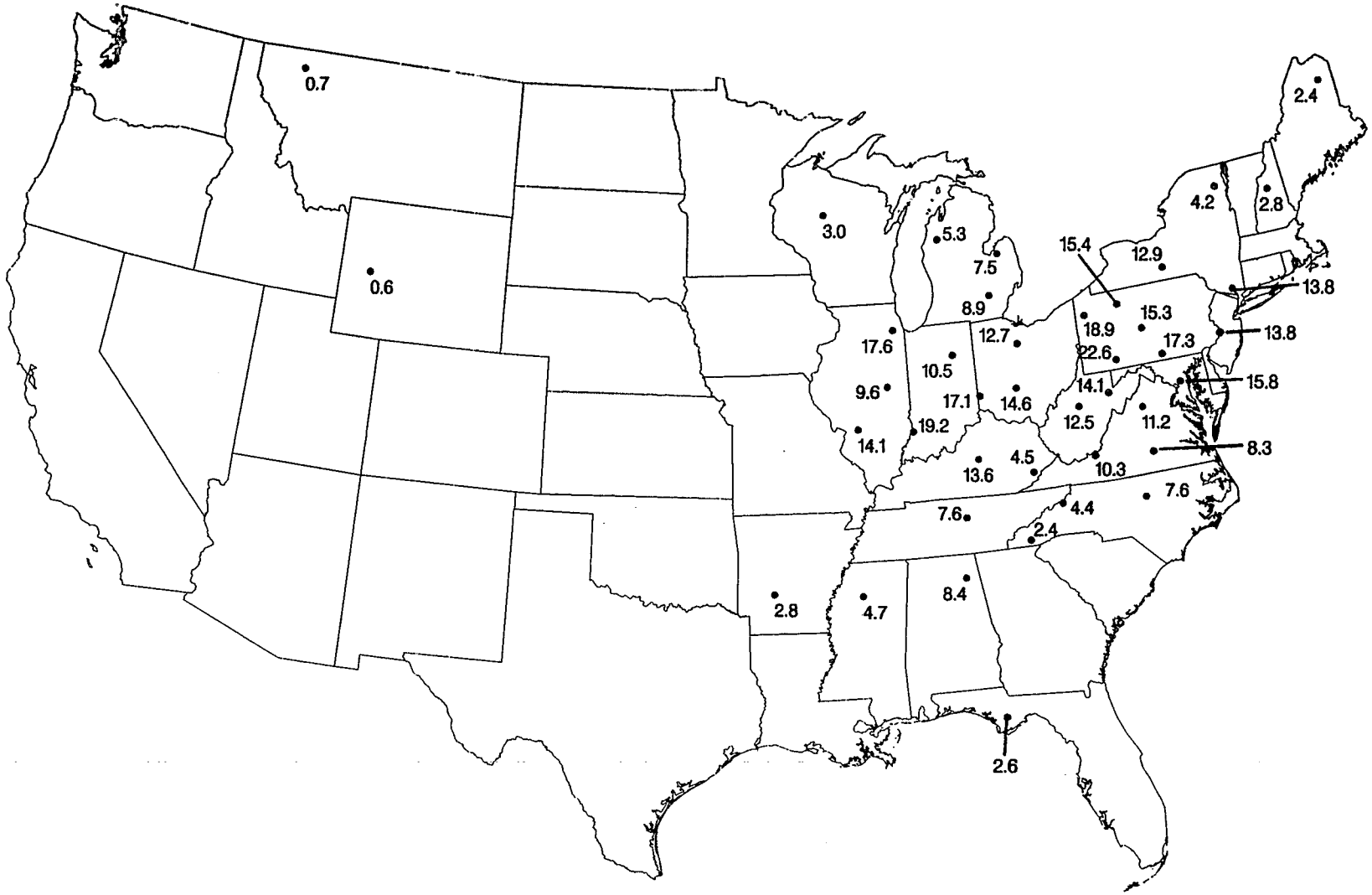


Figure 3-7. Mean annual SO_2 concentrations ($\mu g/m^3$) for 1989

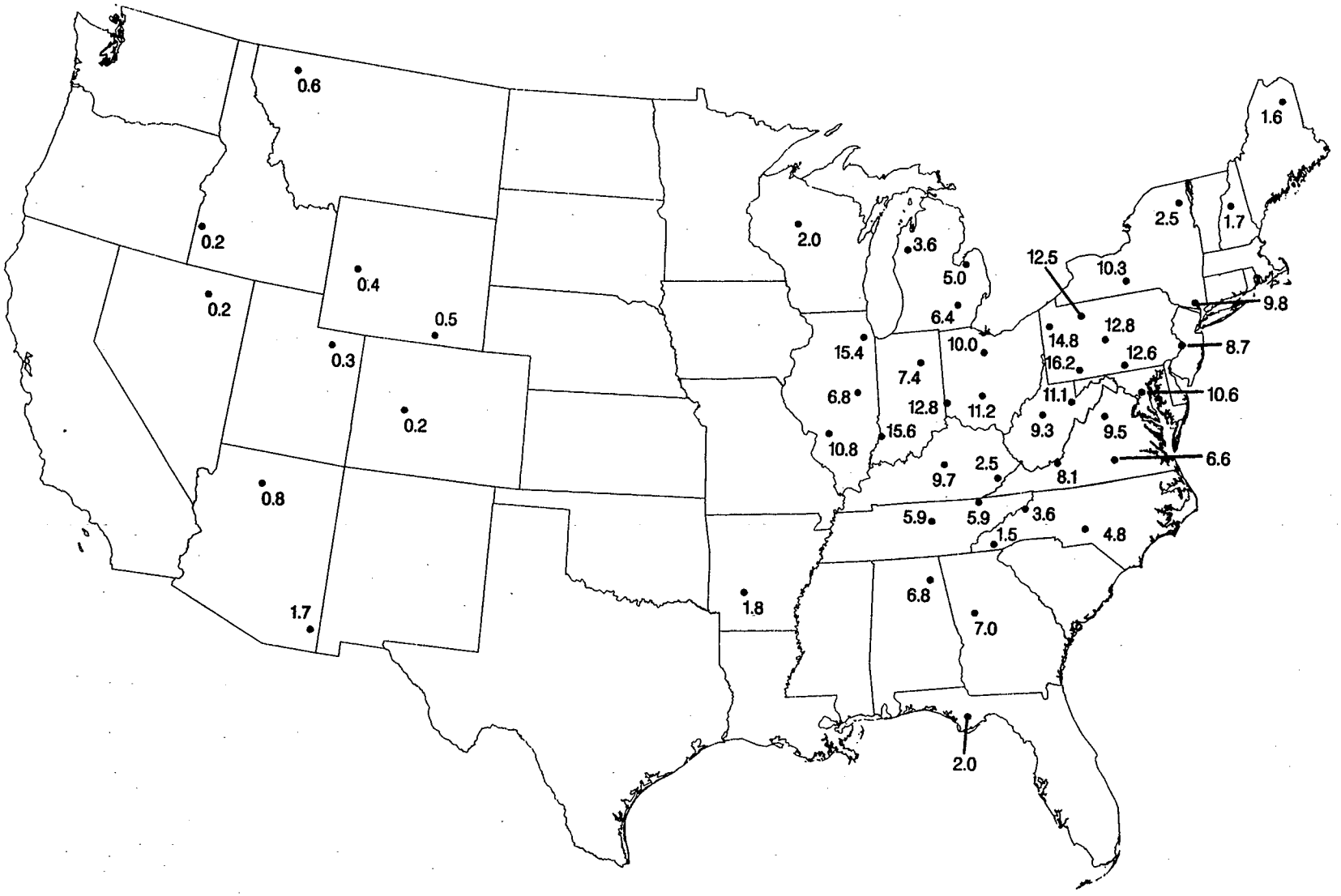


Figure 3-8. Mean annual SO_2 concentrations ($\mu g/m^3$) for 1992

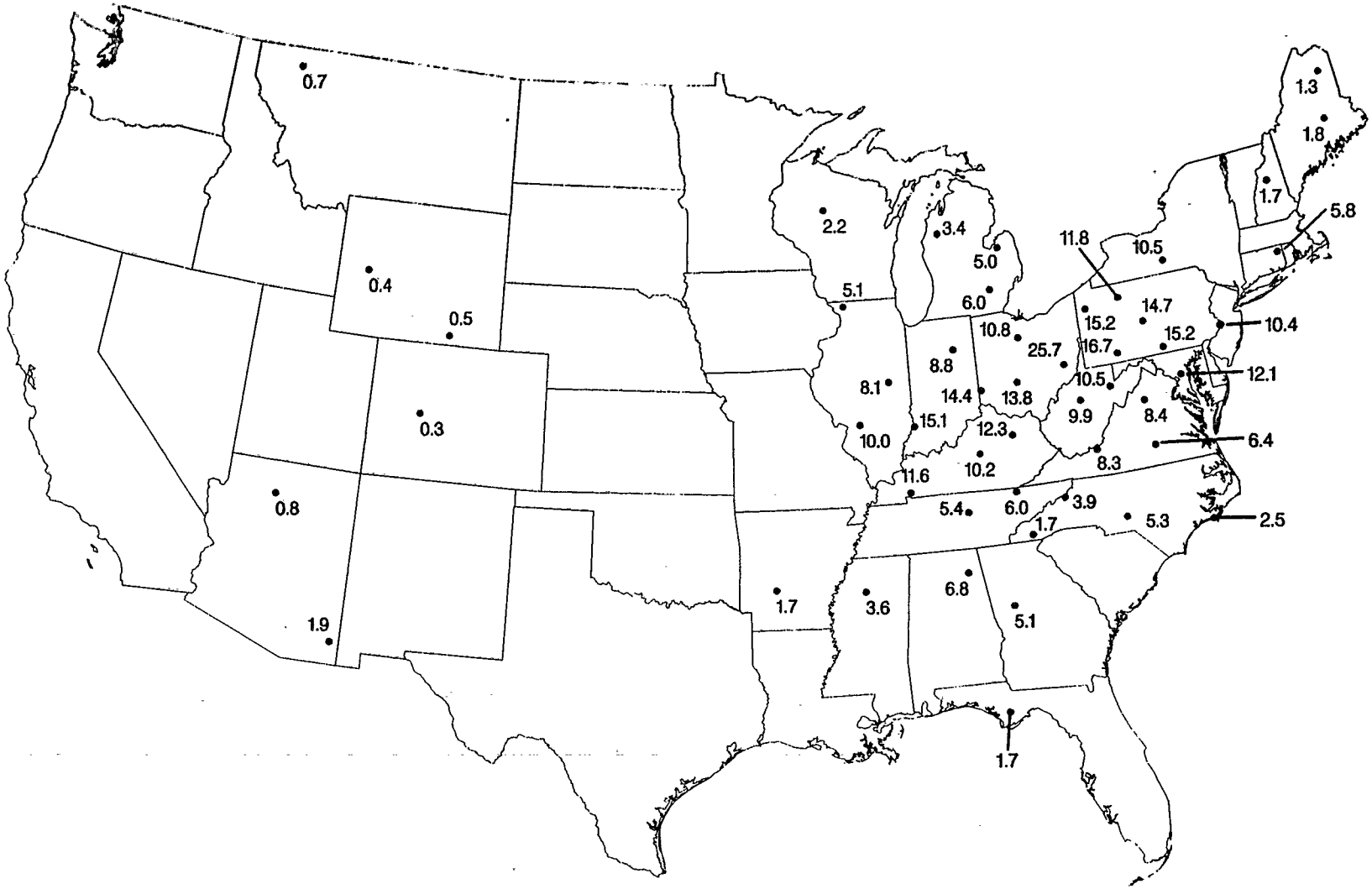


Figure 3-9. Mean annual SO_2 concentrations ($\mu g/m^3$) for 1994

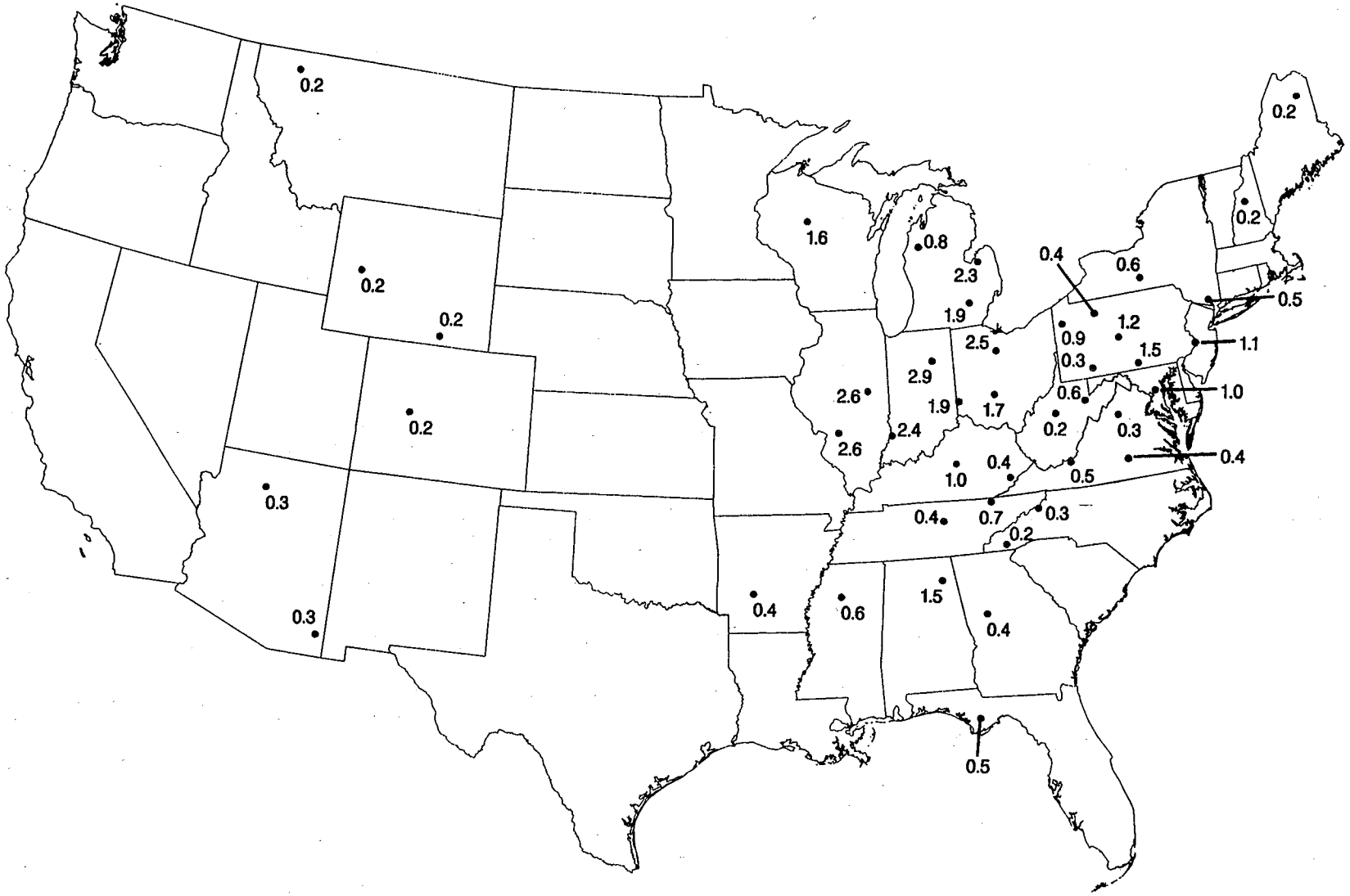


Figure 3-10. Average NO_3^- concentrations ($\mu g/m^3$) from 1989 to 1994

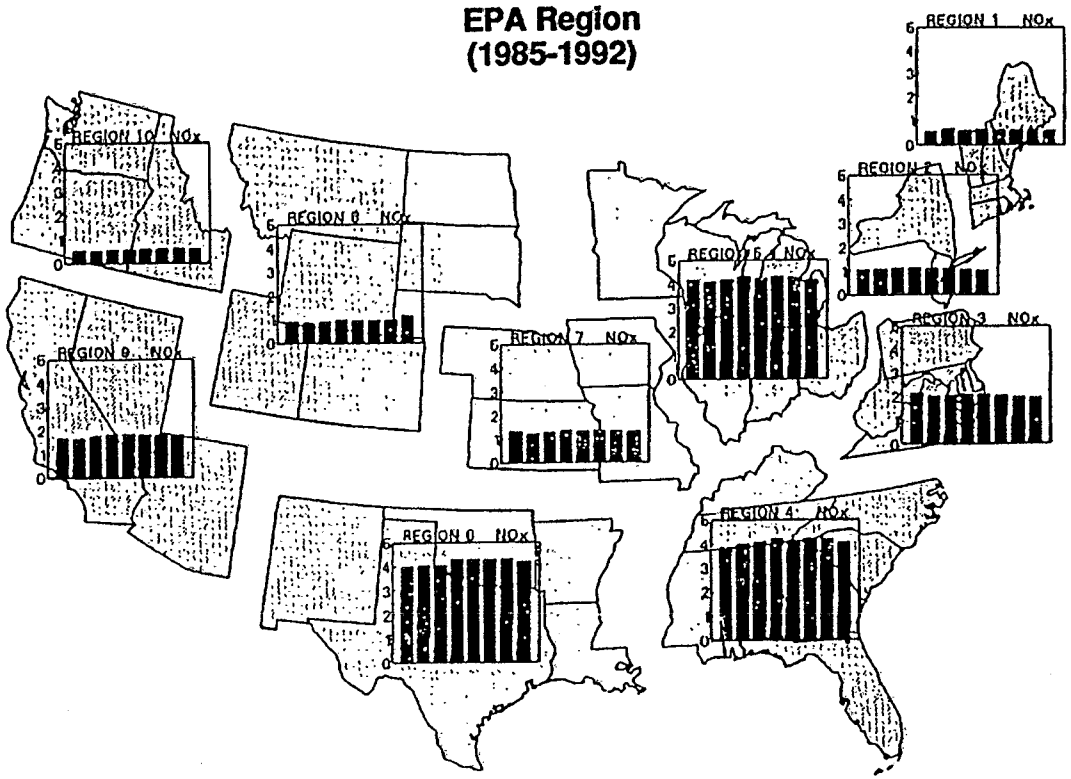


Figure 3-11. NO_x emissions (10^6 metric tons) by EPA Region (1985 to 1992)

SOURCE: EPA, 1996.

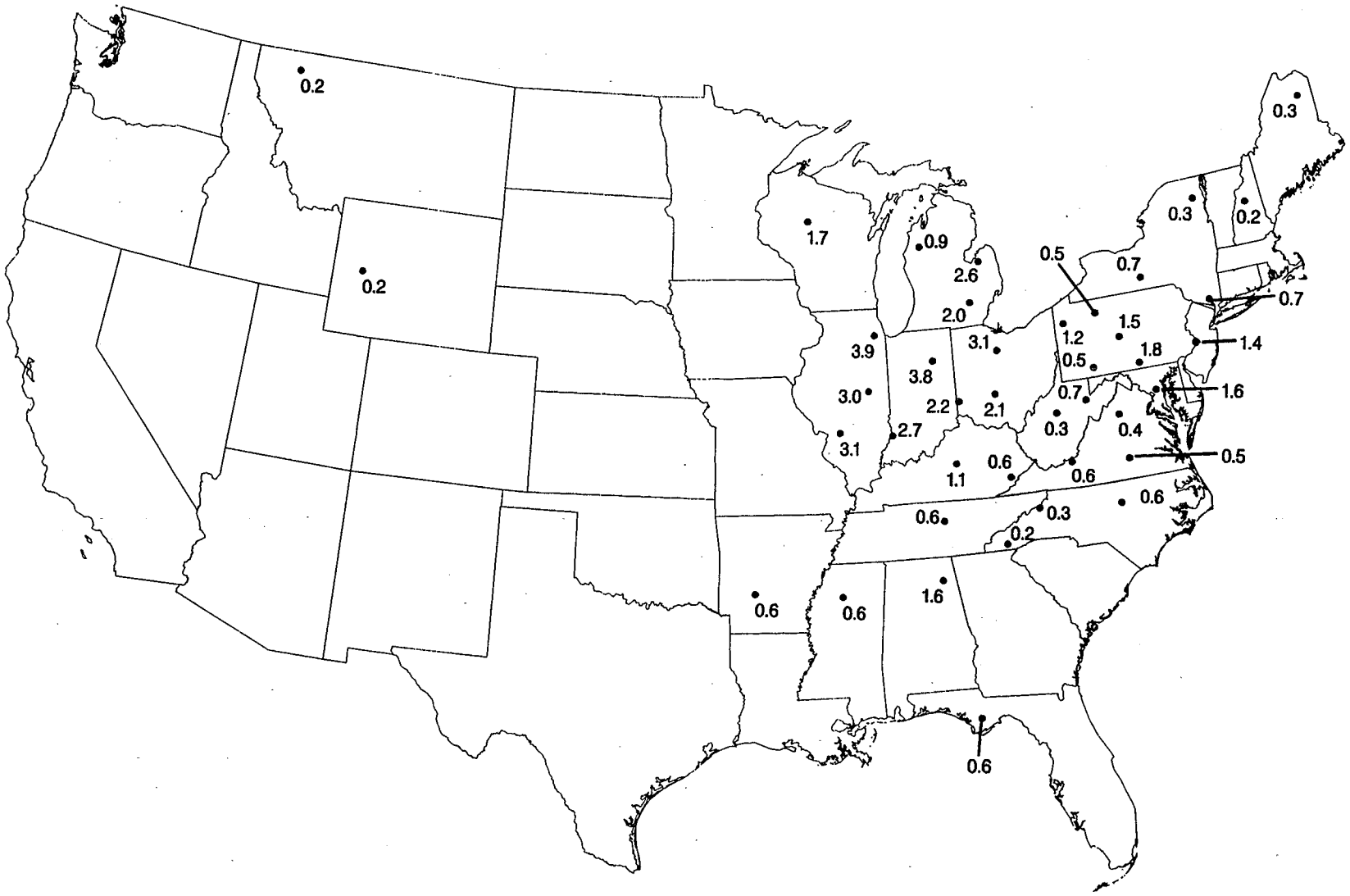


Figure 3-12. Mean annual NO_3^- concentrations ($\mu g/m^3$) for 1989

Figure 3-13. Mean annual NO_3^- concentrations ($\mu g/m^3$) for 1992

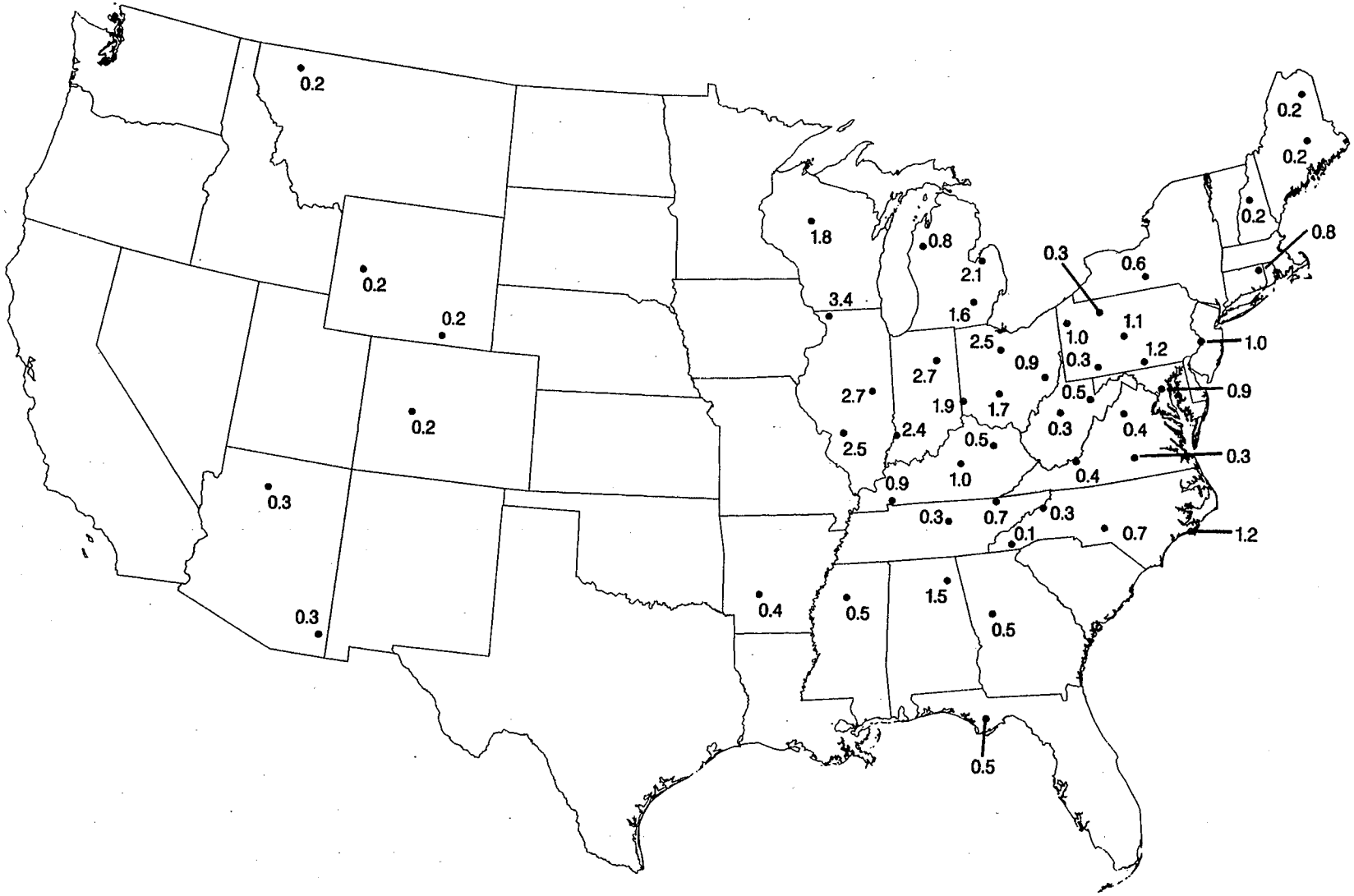


Figure 3-14. Mean annual NO_3 concentrations ($\mu g/m^3$) for 1994

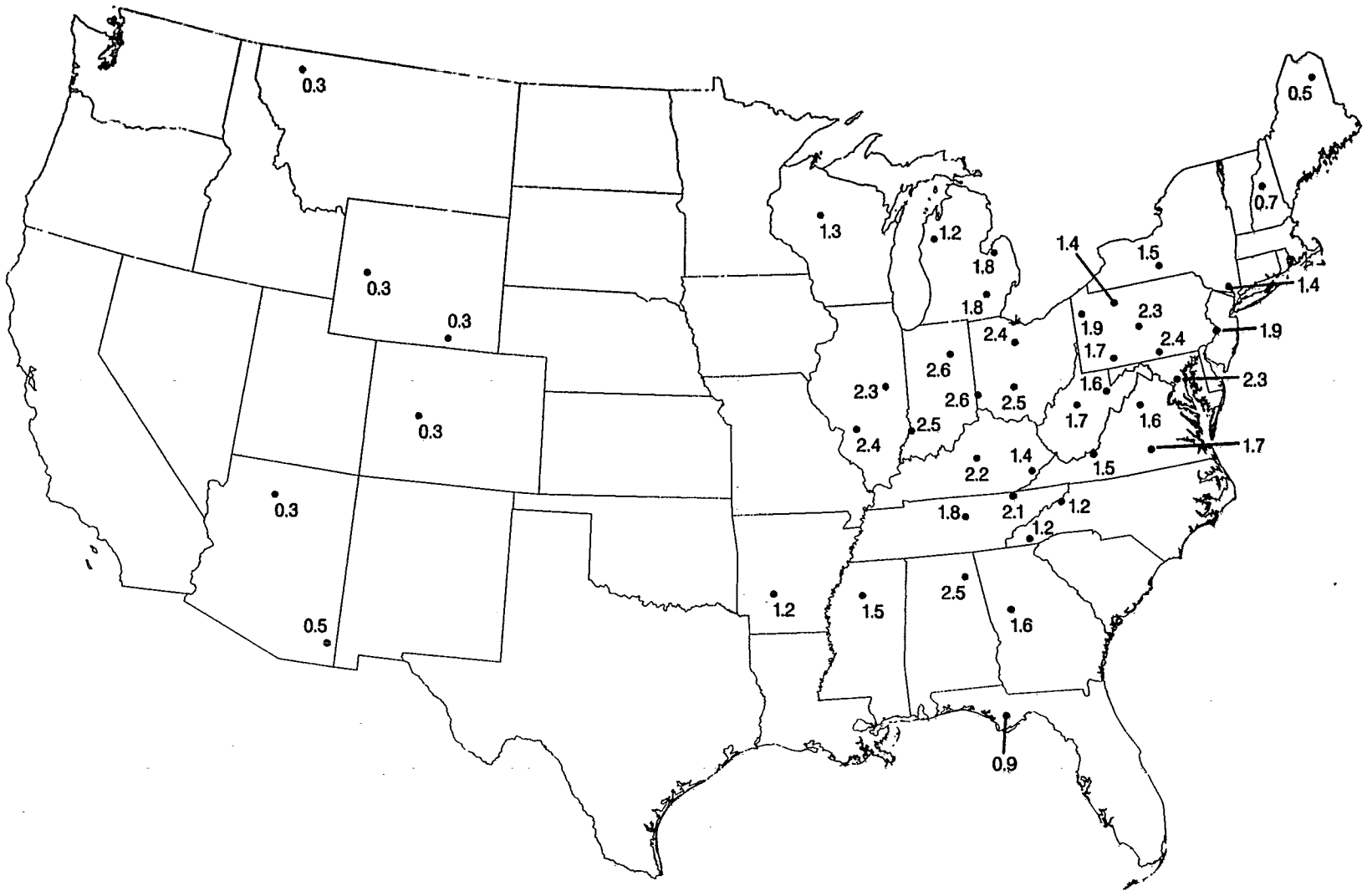


Figure 3-15. Average NH_4^+ concentrations ($\mu g/m^3$) from 1989 to 1994

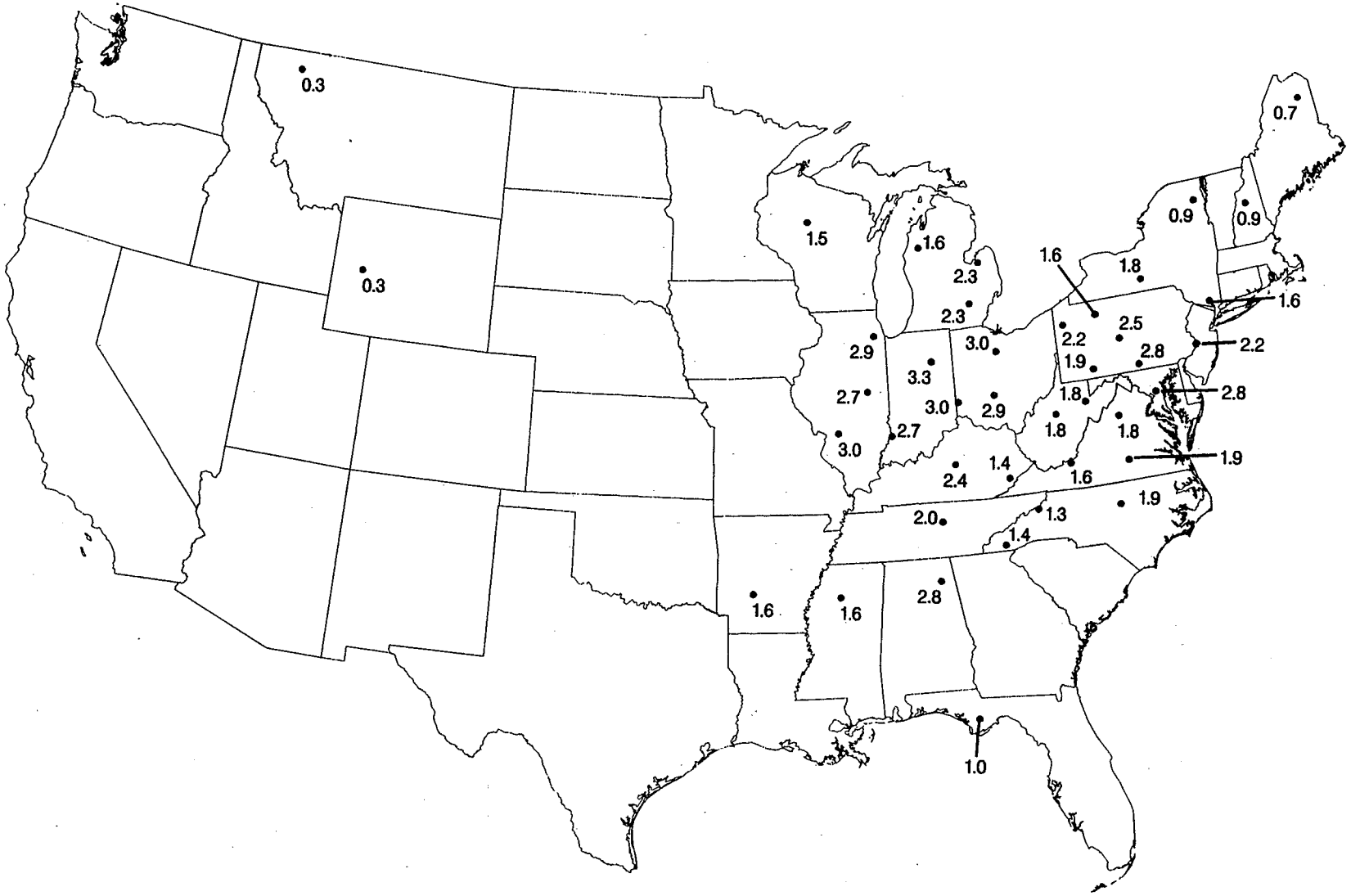


Figure 3-16. Mean annual NH_4^+ concentrations ($\mu g/m^3$) for 1989

Figure 3-17. Mean annual NH_4^+ concentrations ($\mu g/m^3$) for 1992

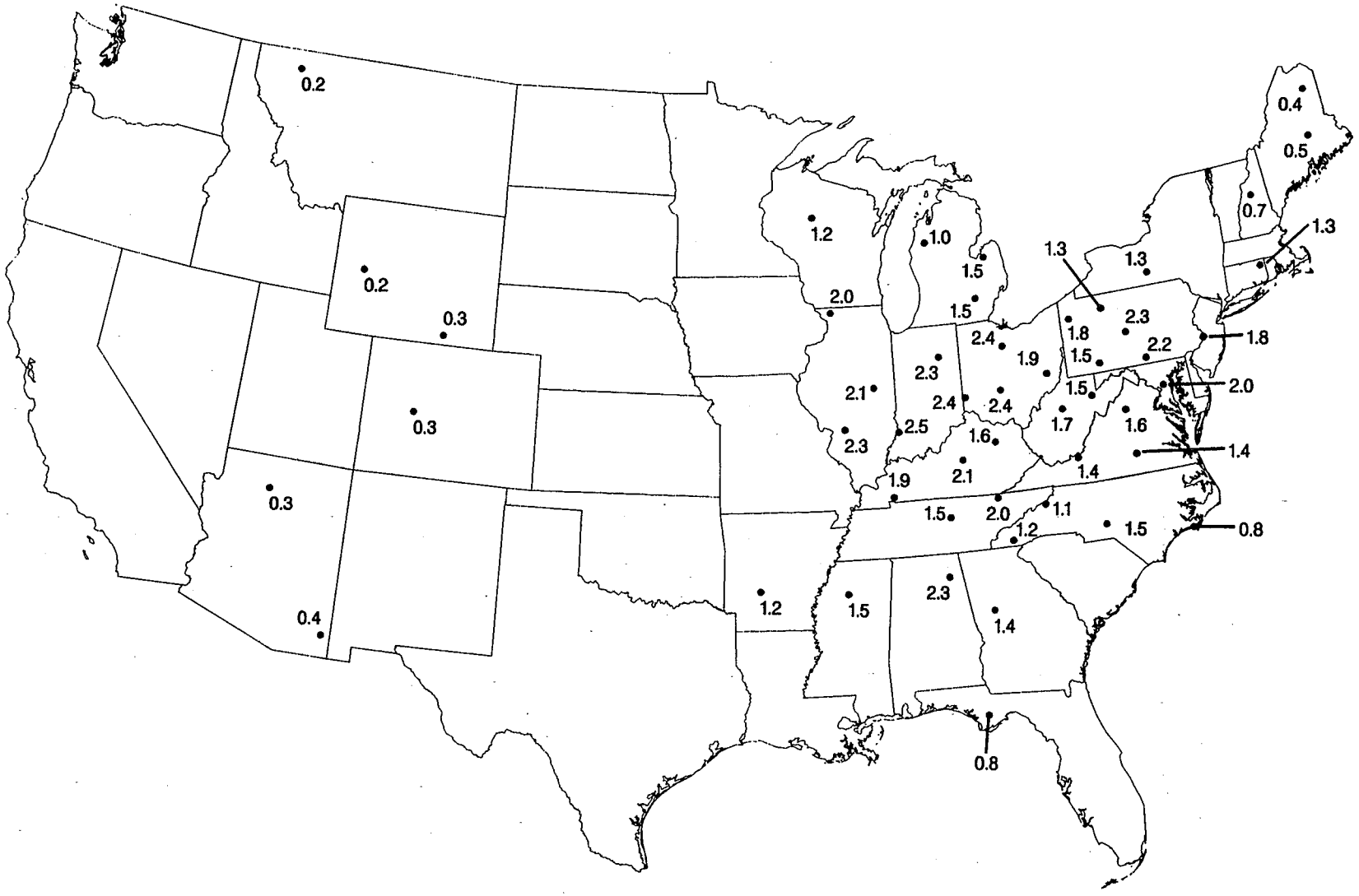


Figure 3-18. Mean annual NH_4^+ concentrations ($\mu g/m^3$) for 1994

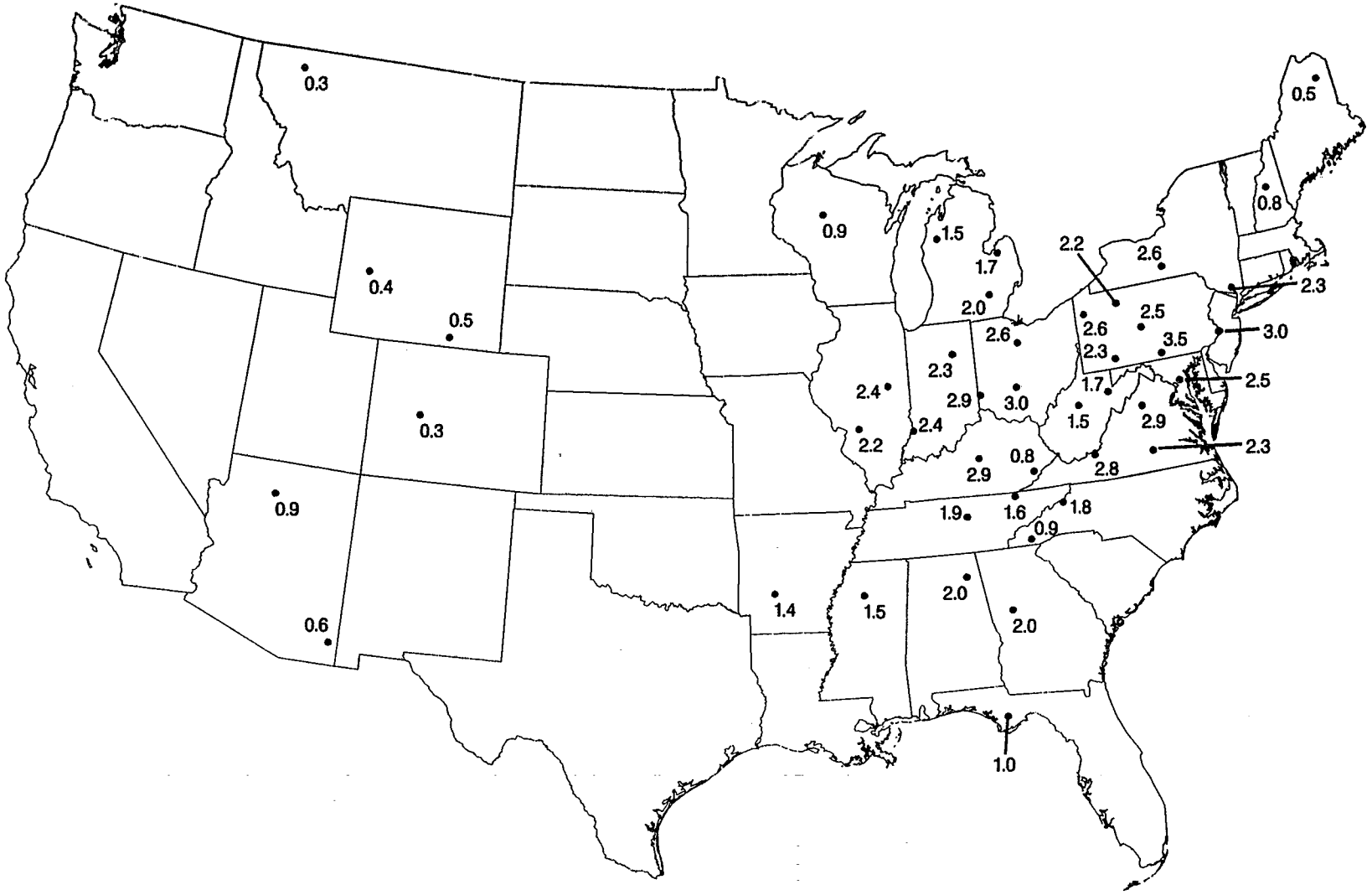


Figure 3-19. Average HNO_3 concentrations ($\mu g/m^3$) from 1989 to 1994

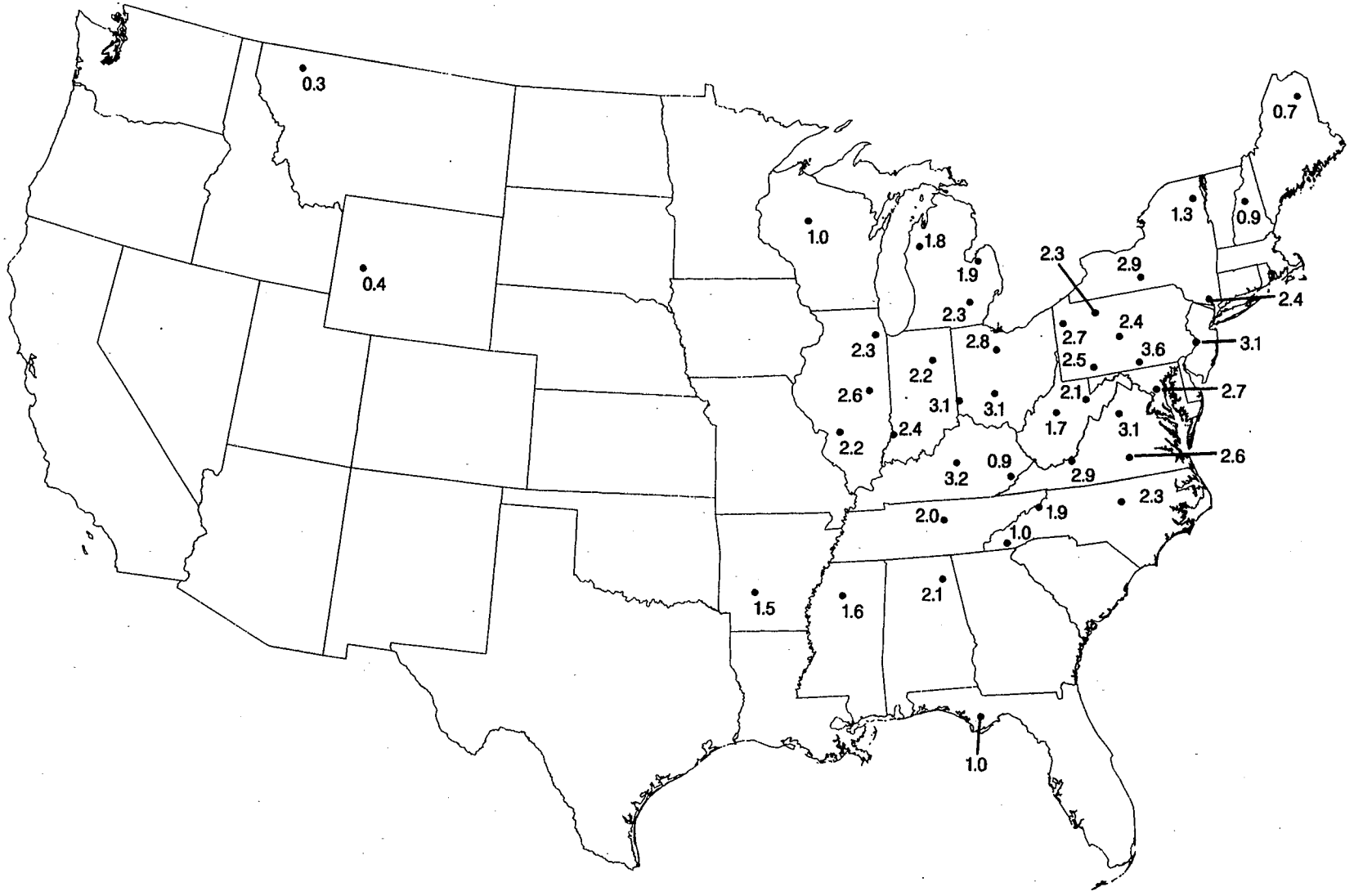


Figure 3-20. Mean annual HNO_3 concentrations ($\mu g/m^3$) for 1989

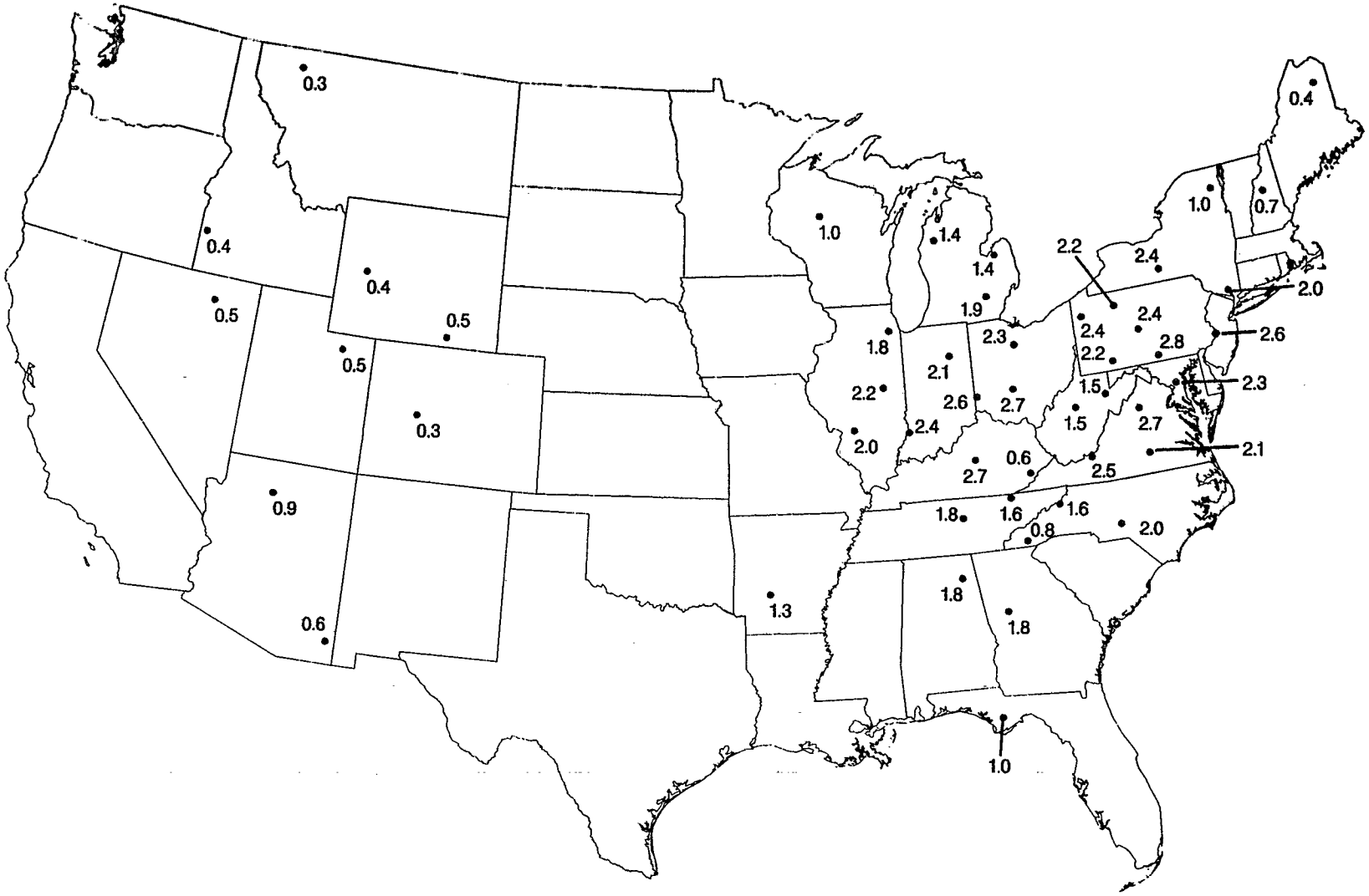


Figure 3-21. Mean annual HNO_3 concentrations ($\mu g/m^3$) for 1992

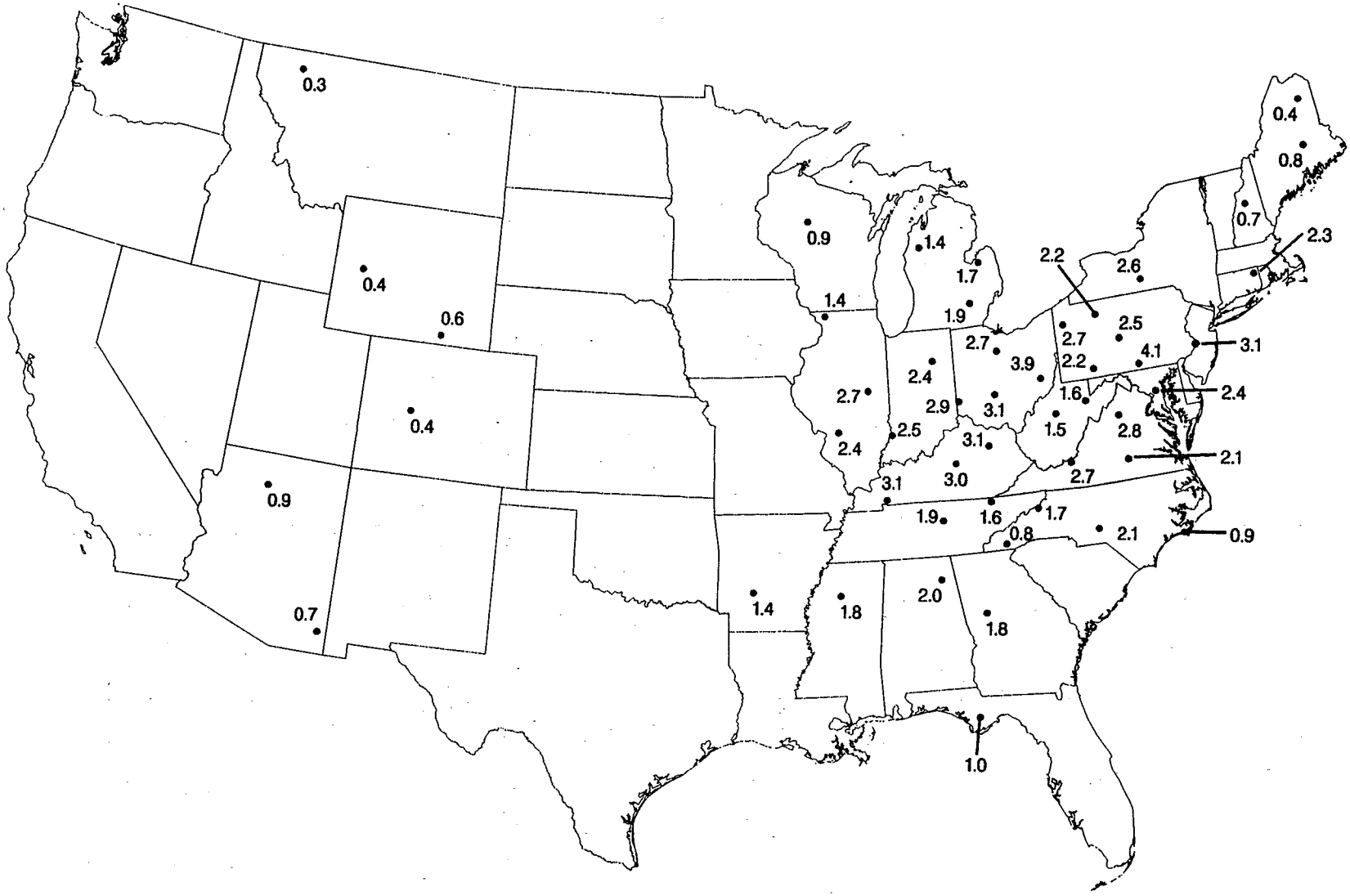


Figure 3-22. Mean annual HNO_3 concentrations ($\mu g/m^3$) for 1994

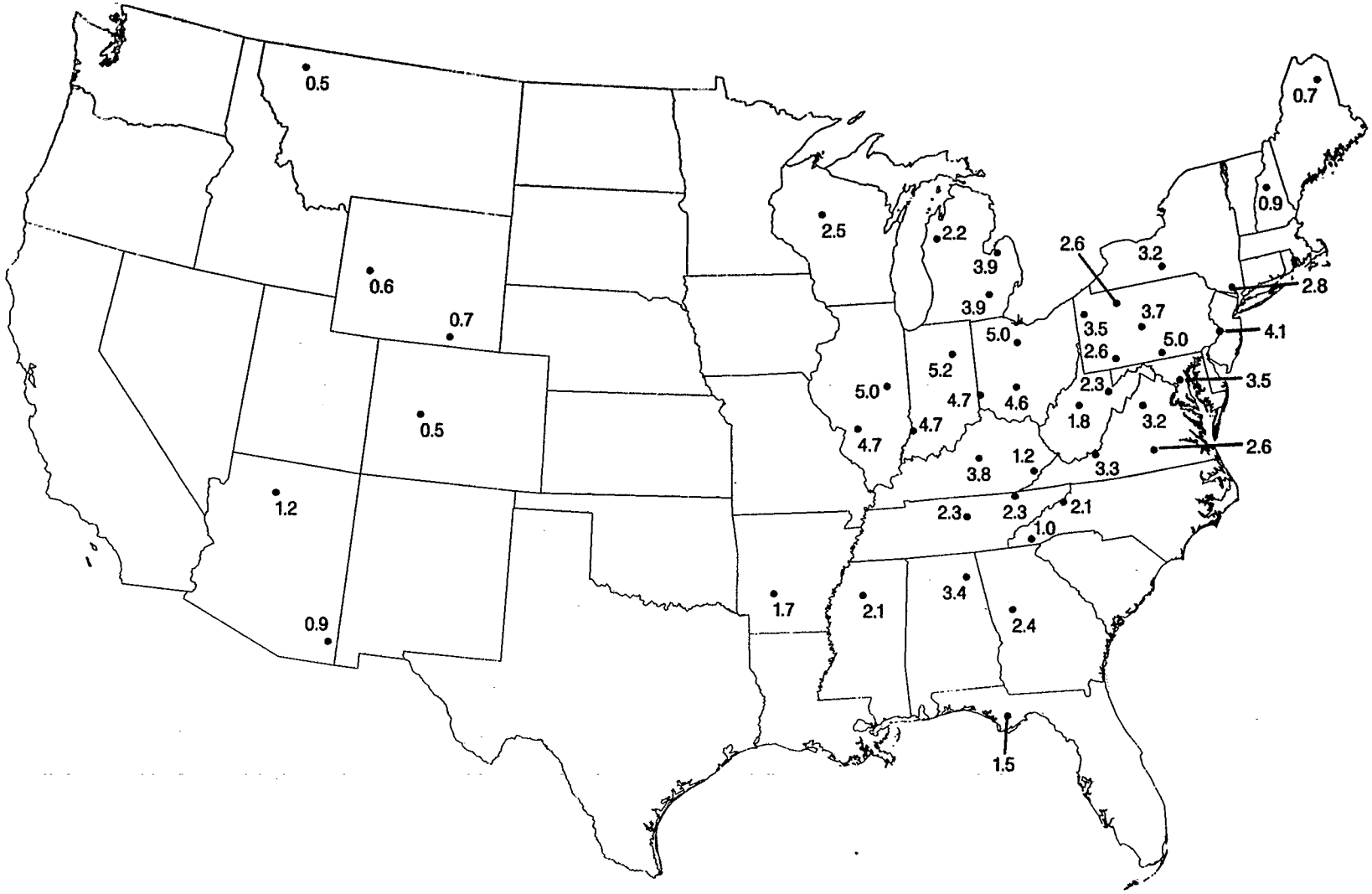


Figure 3-23. Average total NO_3^- concentrations ($\mu g/m^3$) from 1989 to 1994

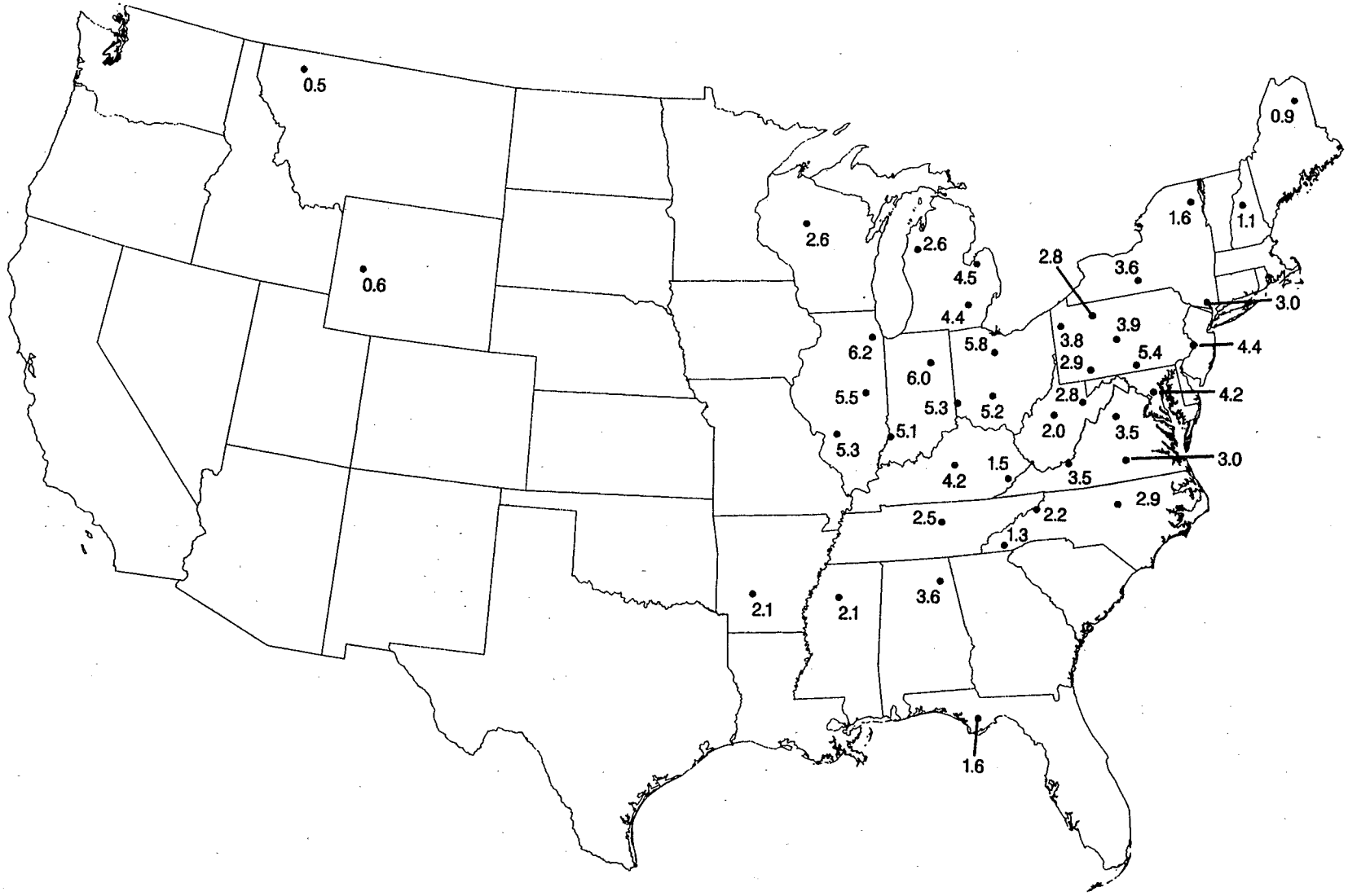


Figure 3-24. Mean annual total NO_3^- concentrations ($\mu g/m^3$) for 1989

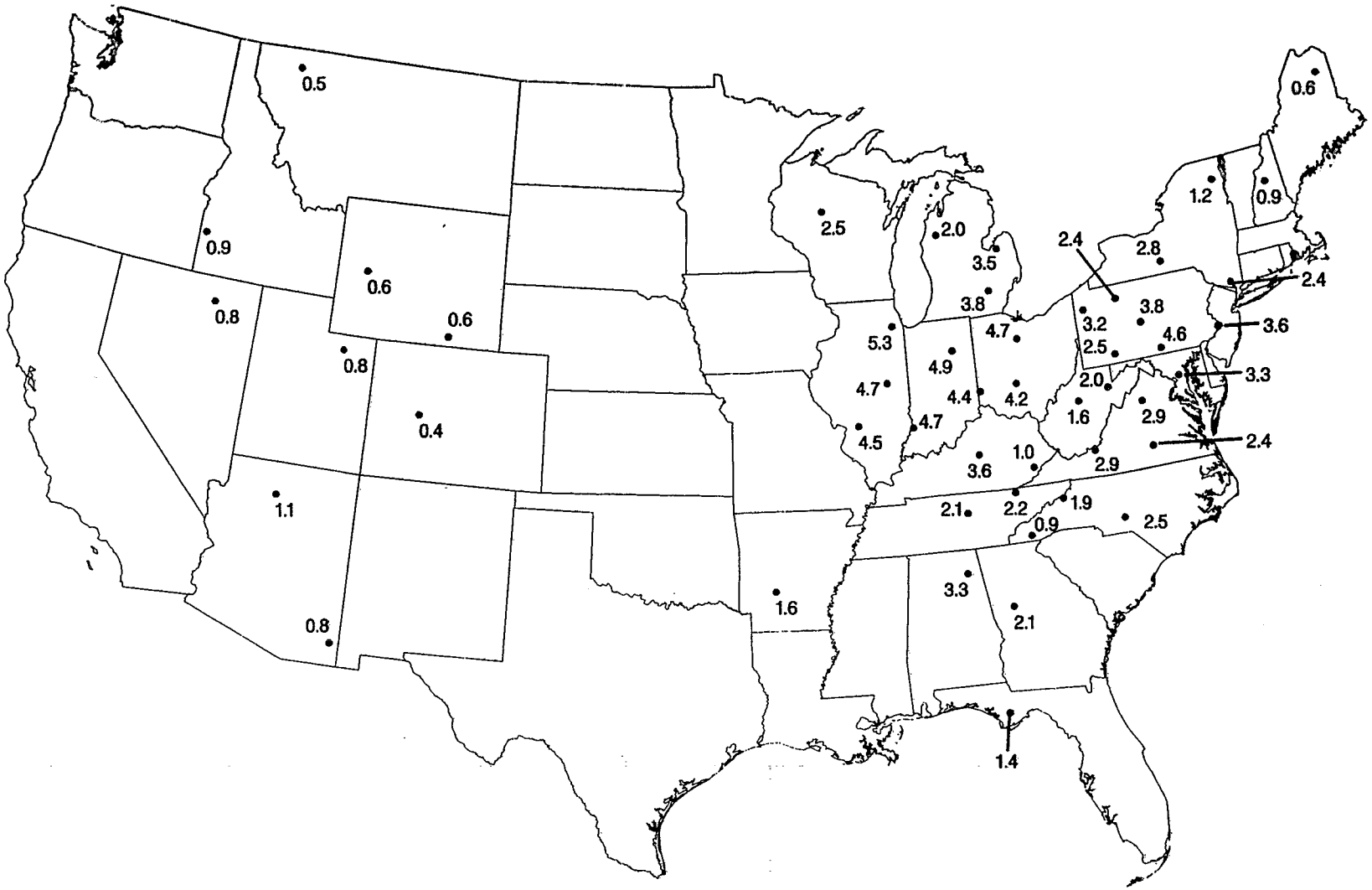


Figure 3-25. Mean annual total NO_3^- concentrations ($\mu g/m^3$) for 1992

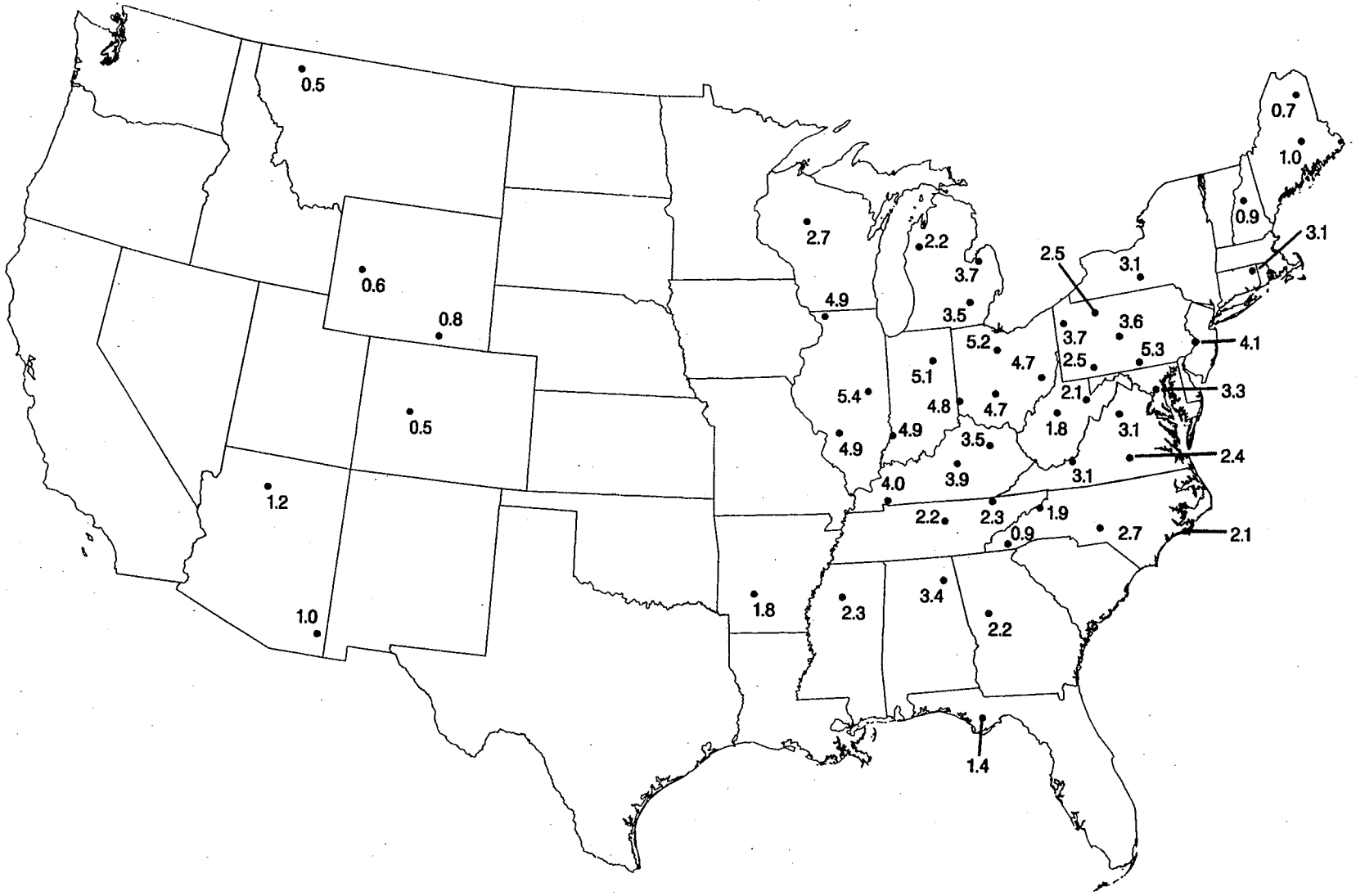


Figure 3-26. Mean annual total NO_3^- concentrations ($\mu g/m^3$) for 1994

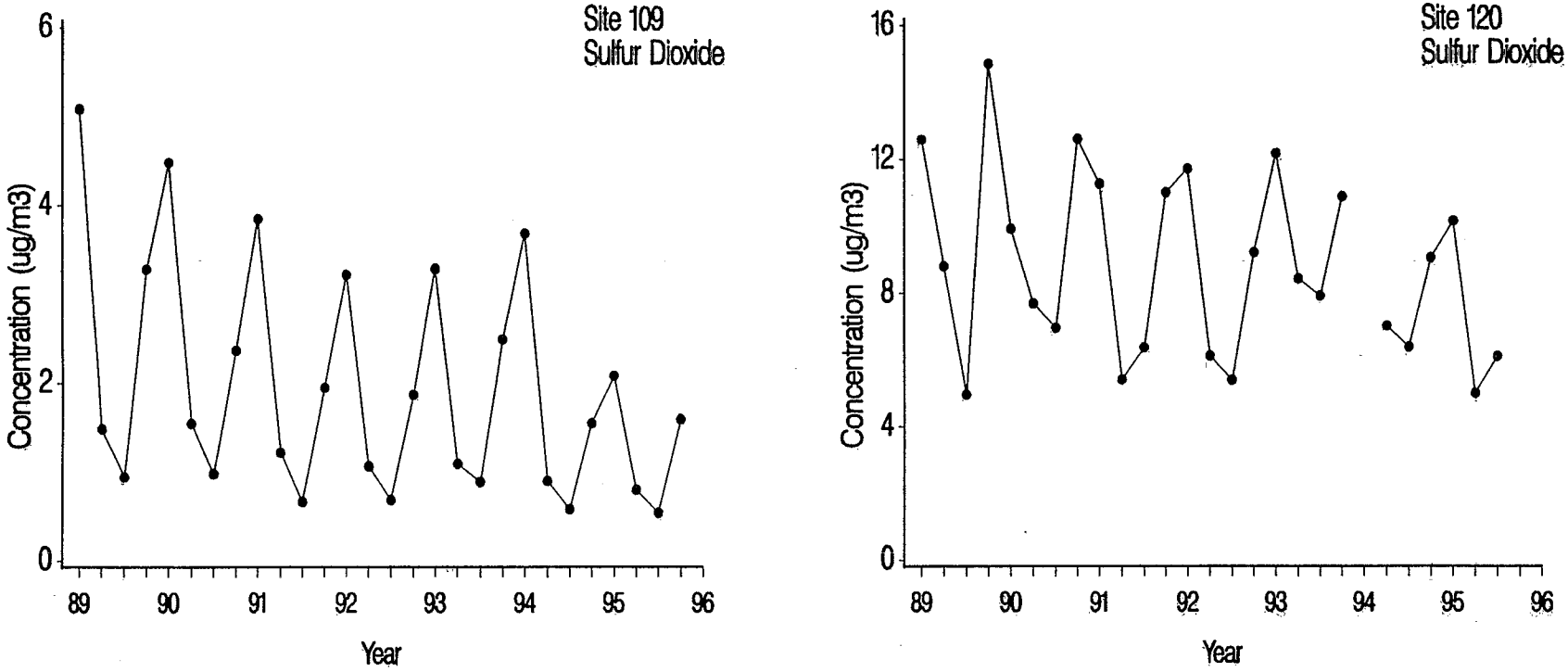


Figure 3-27. Quarterly average concentrations for SO_2 ($\mu g/m^3$) at two sites

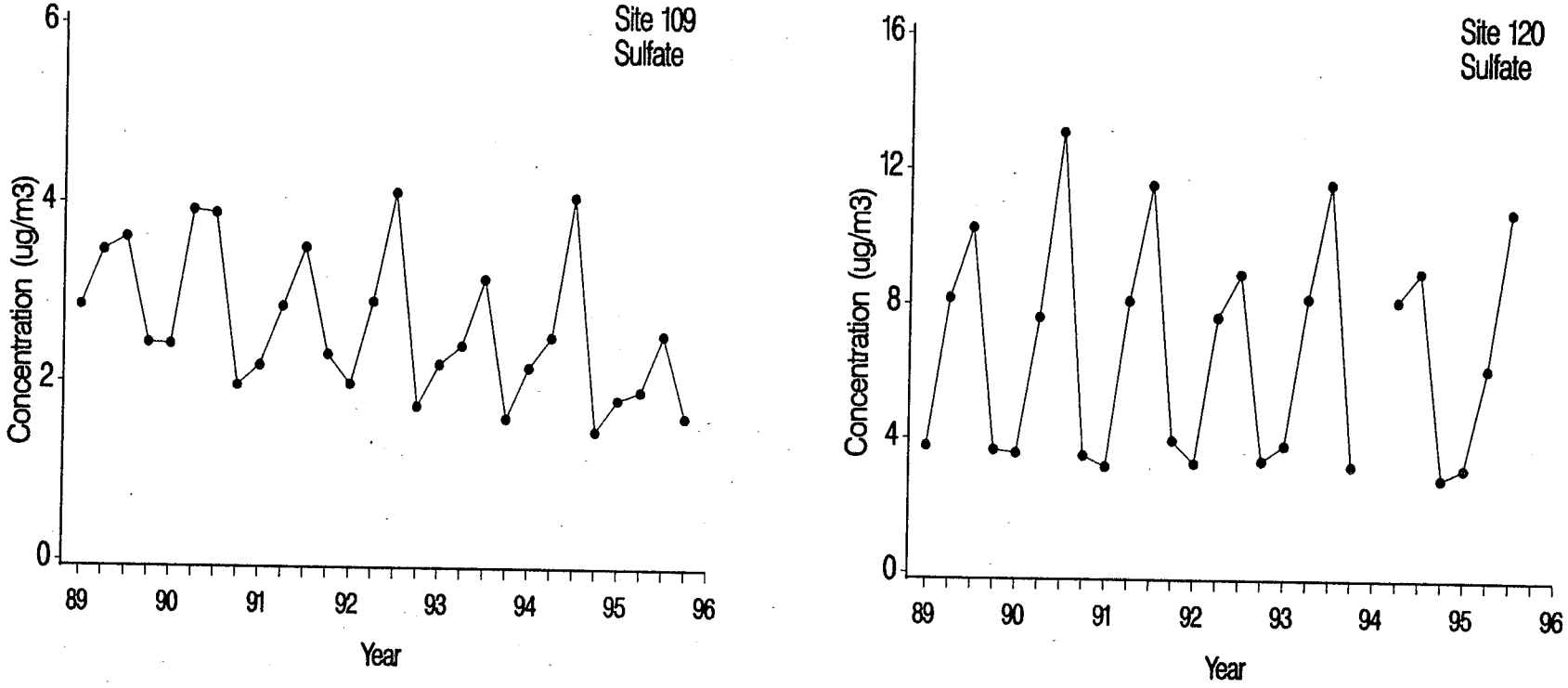


Figure 3-28. Quarterly average concentrations for SO_4^{2-} ($\mu g/m^3$) at two sites

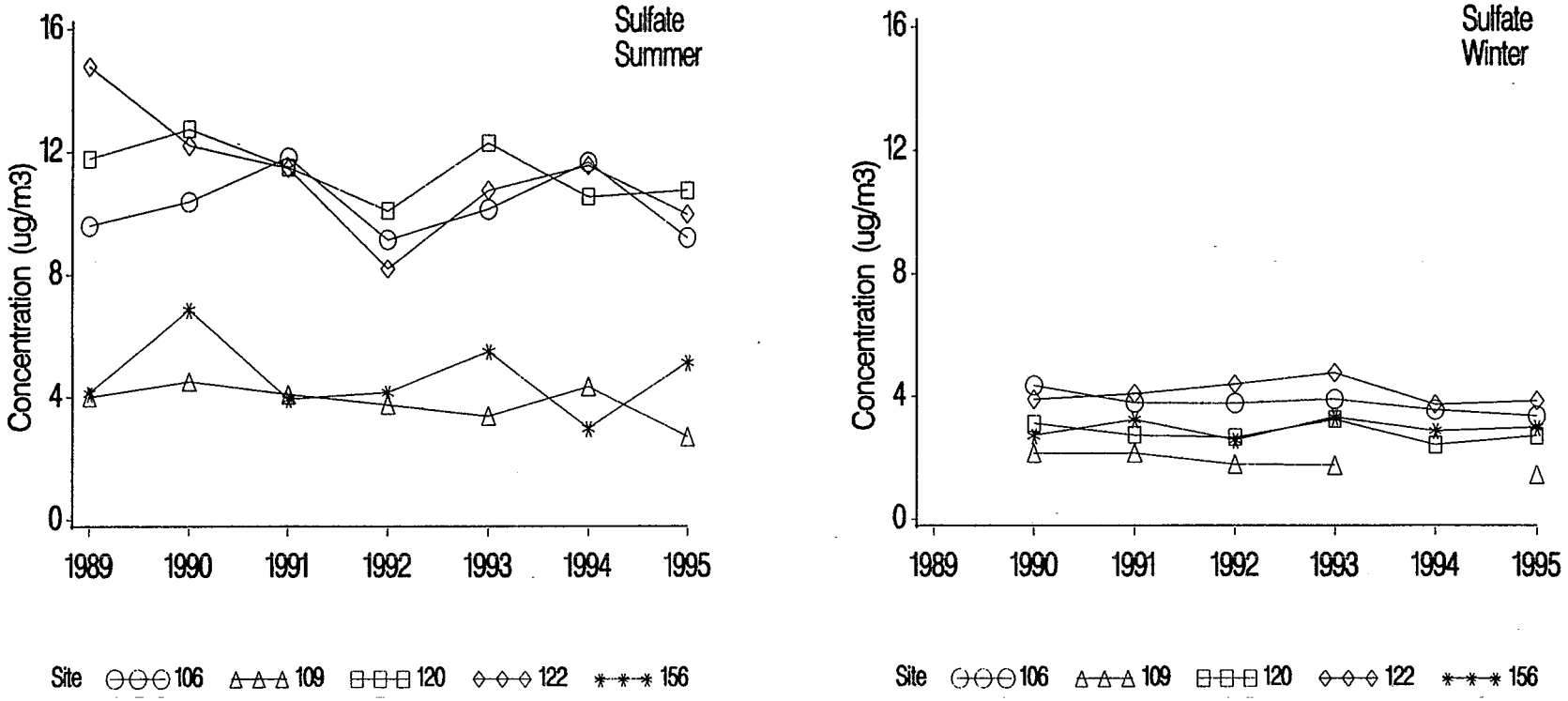


Figure 3-29. Seasonal (summer vs. winter) variability of SO_4^{2-} ($\mu g/m^3$) for five eastern sites

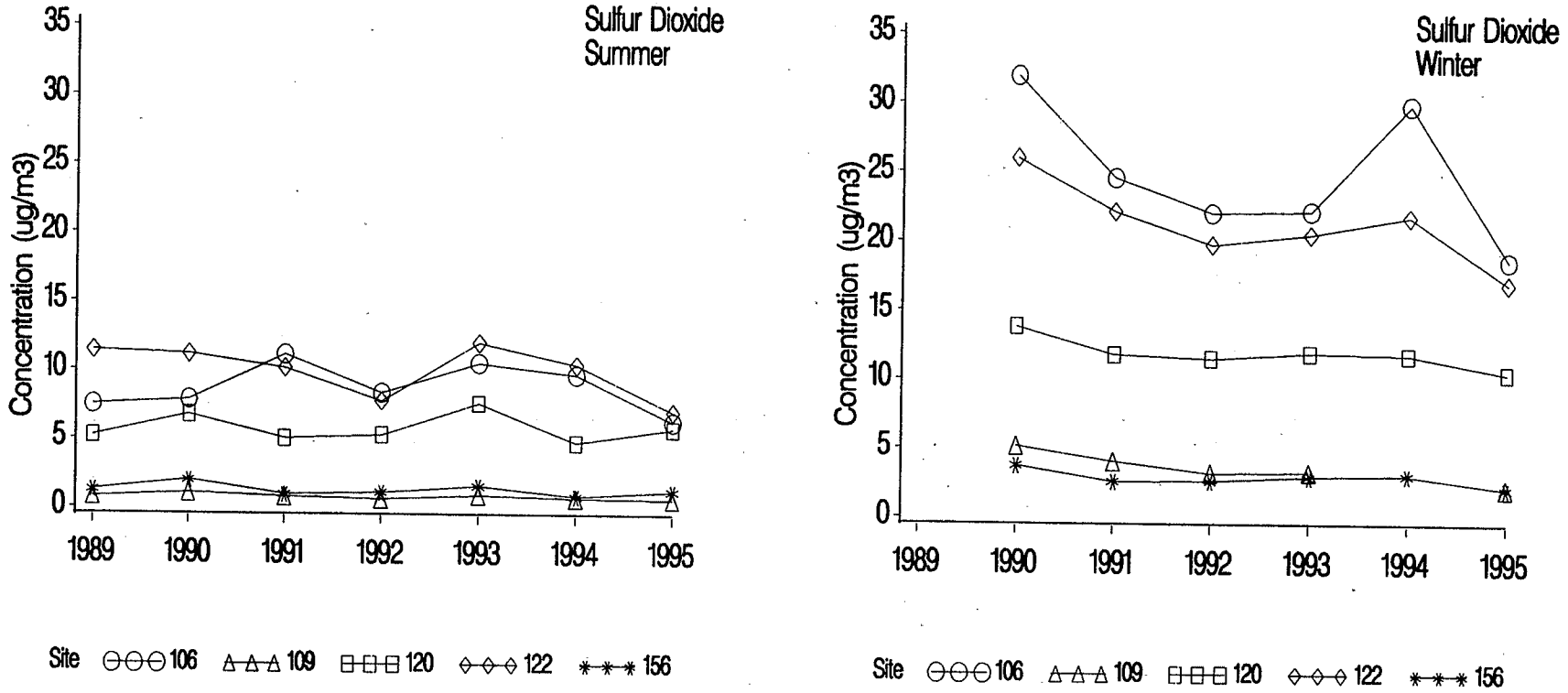


Figure 3-30. Seasonal (summer vs. winter) variability of SO_2 ($\mu g/m^3$) for five eastern sites

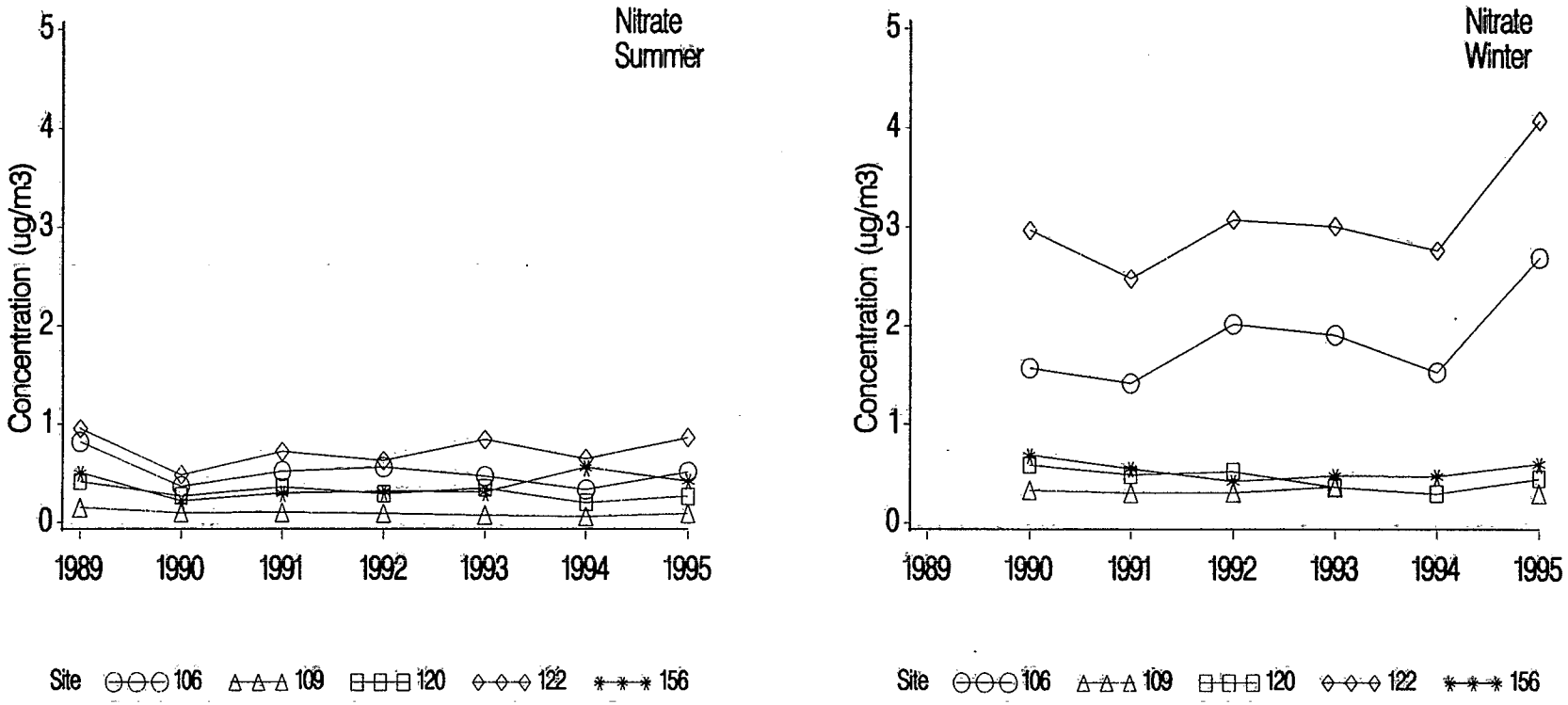


Figure 3-31. Seasonal (summer vs. winter) variability of NO_3^- ($\mu g/m^3$) for five eastern sites

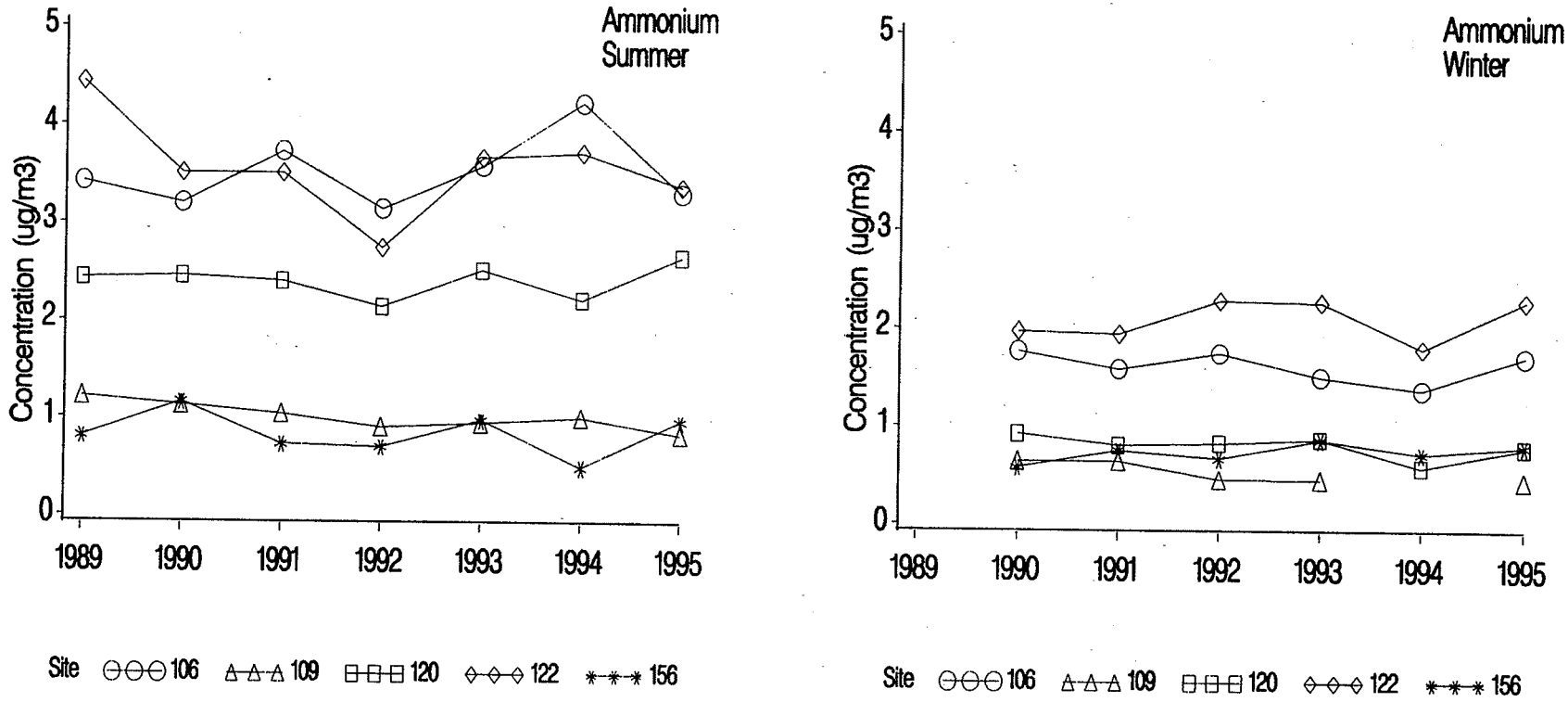


Figure 3-32. Seasonal (summer vs. winter) variability of NH_4^+ ($\mu g/m^3$) for five eastern sites

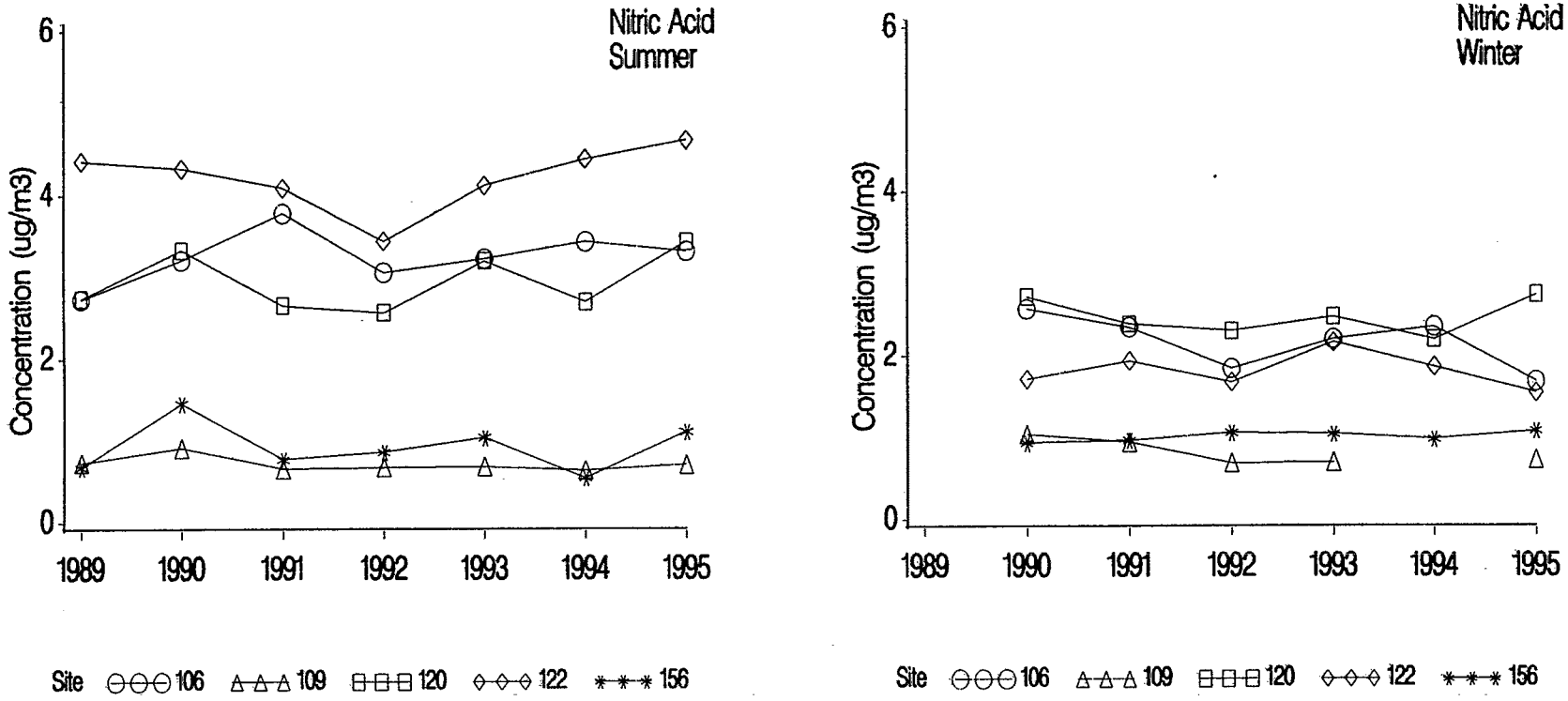


Figure 3-33. Seasonal (summer vs. winter) variability of HNO_3 ($\mu g/m^3$) for five eastern sites

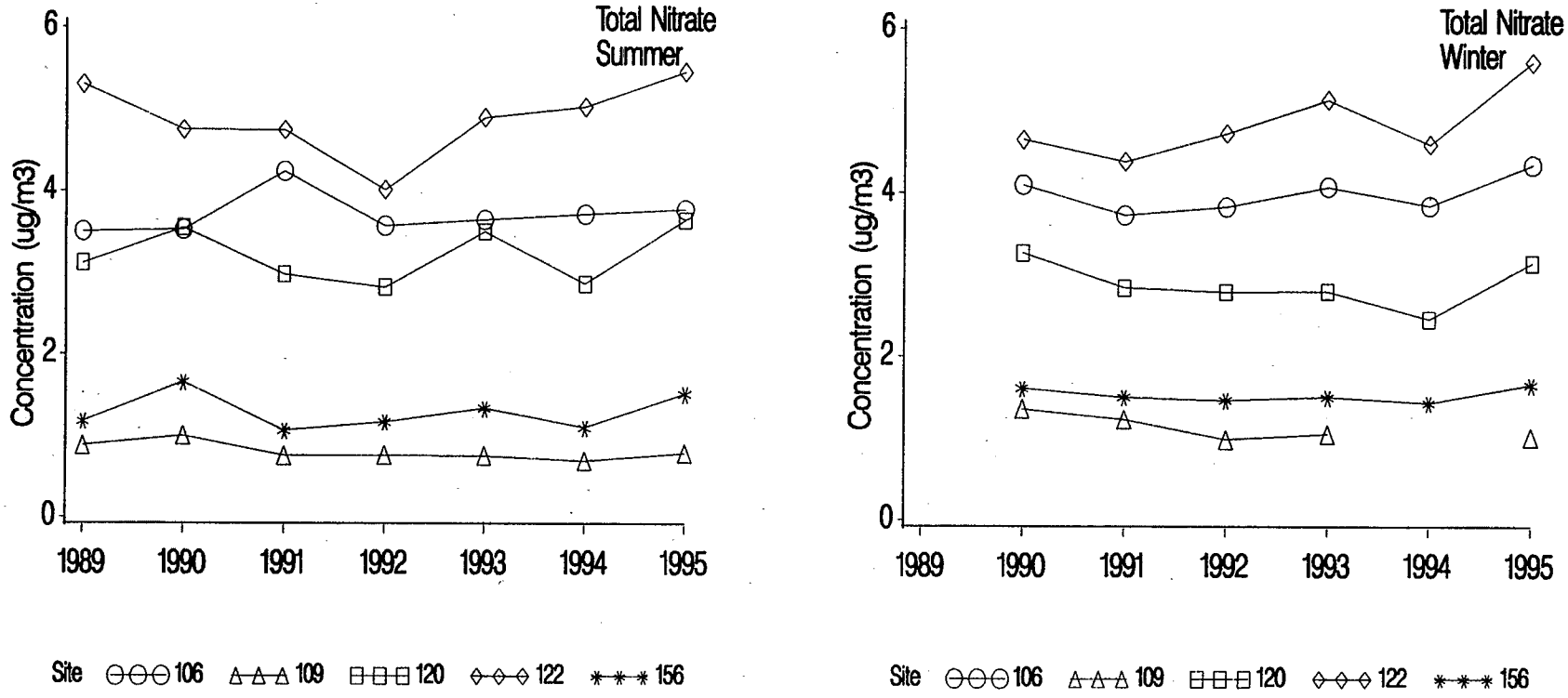


Figure 3-34. Seasonal (summer vs. winter) variability of total NO_3^- ($\mu g/m^3$) for five eastern sites

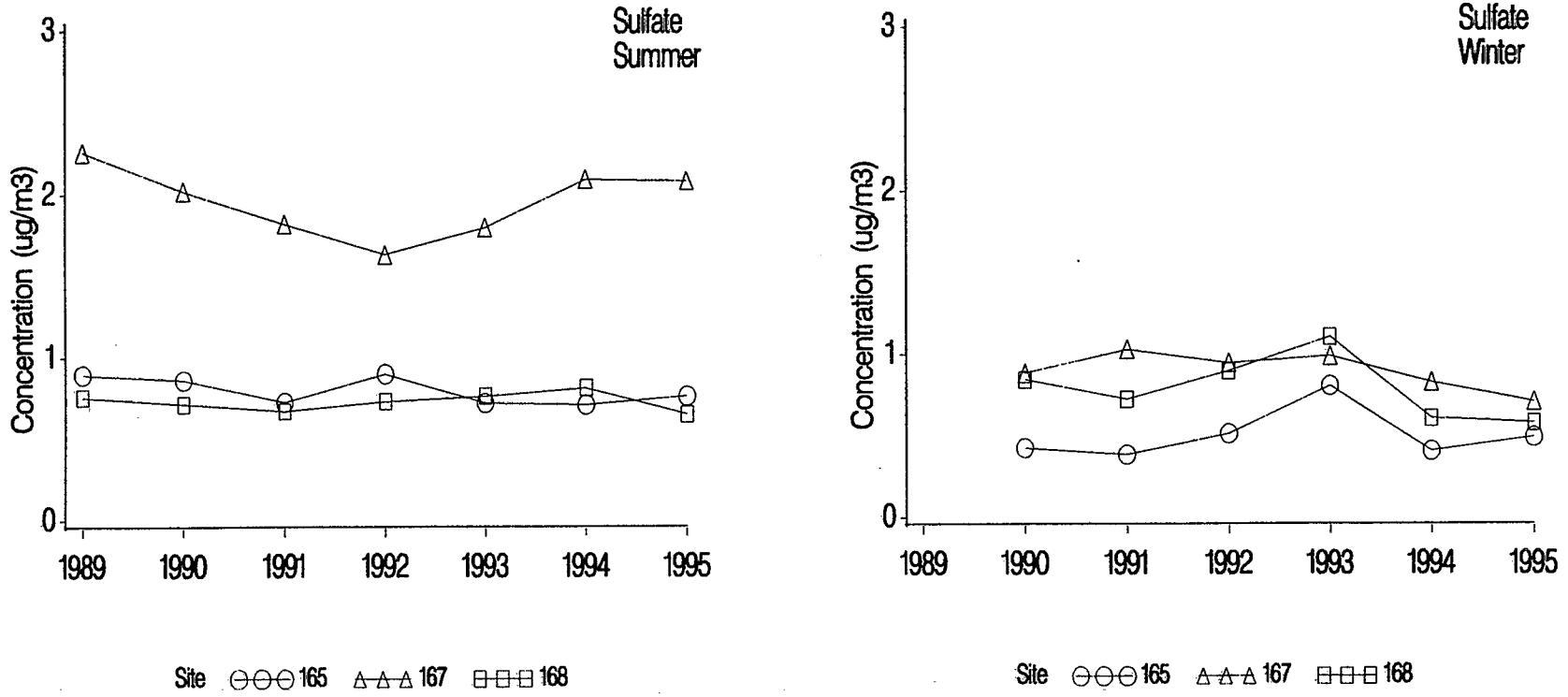


Figure 3-35. Seasonal (summer vs. winter) variability of SO_4^{2-} ($\mu g/m^3$) for three western sites

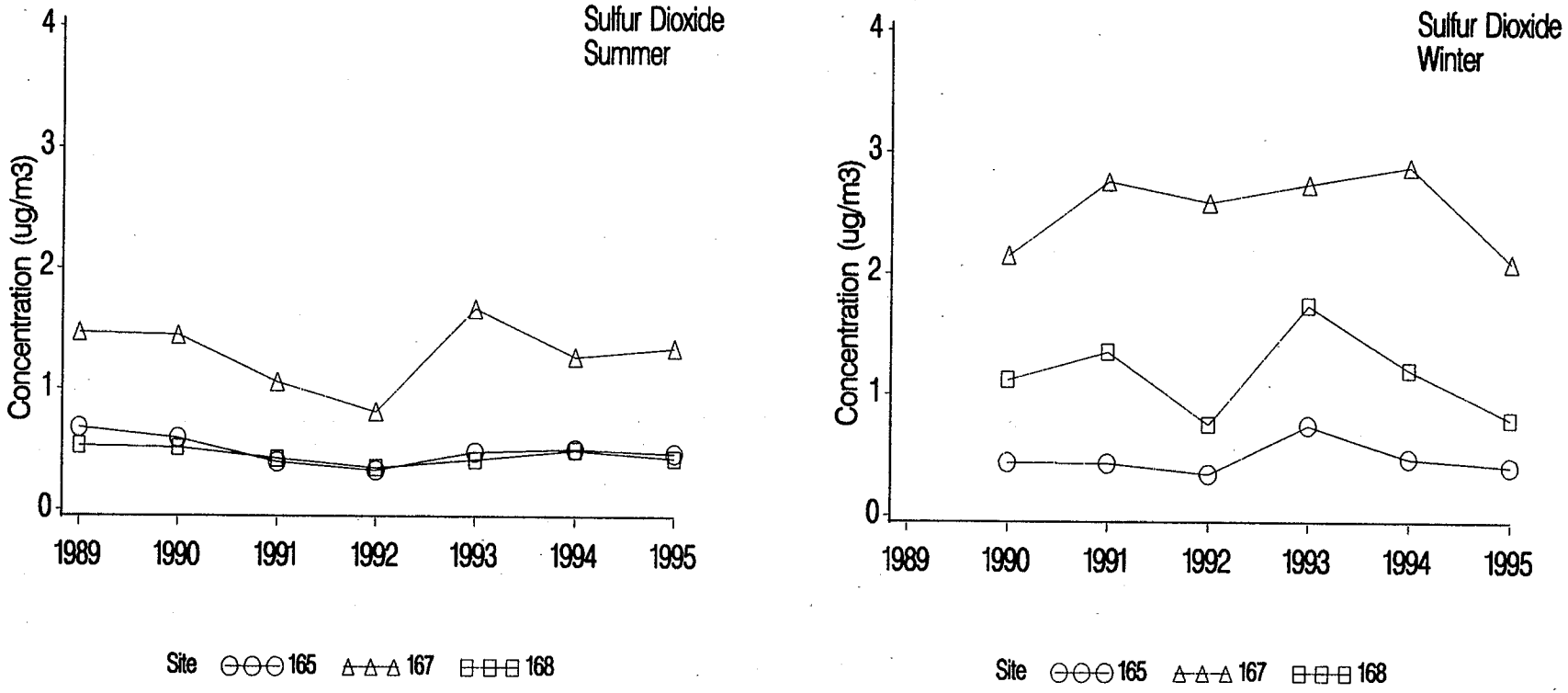


Figure 3-36. Seasonal (summer vs. winter) variability of SO_2 ($\mu g/m^3$) for three western sites

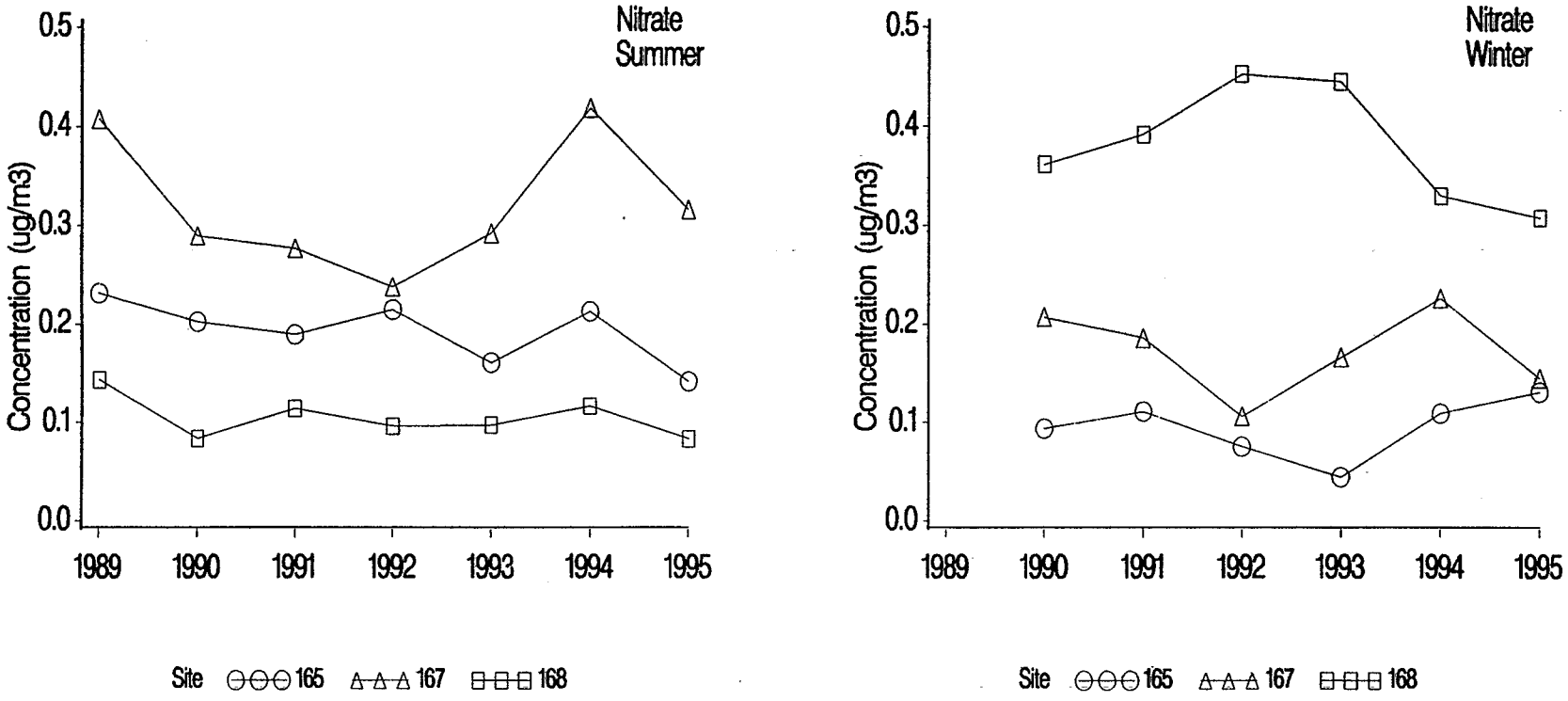


Figure 3-37. Seasonal (summer vs. winter) variability of NO_3^- ($\mu g/m^3$) for three western sites

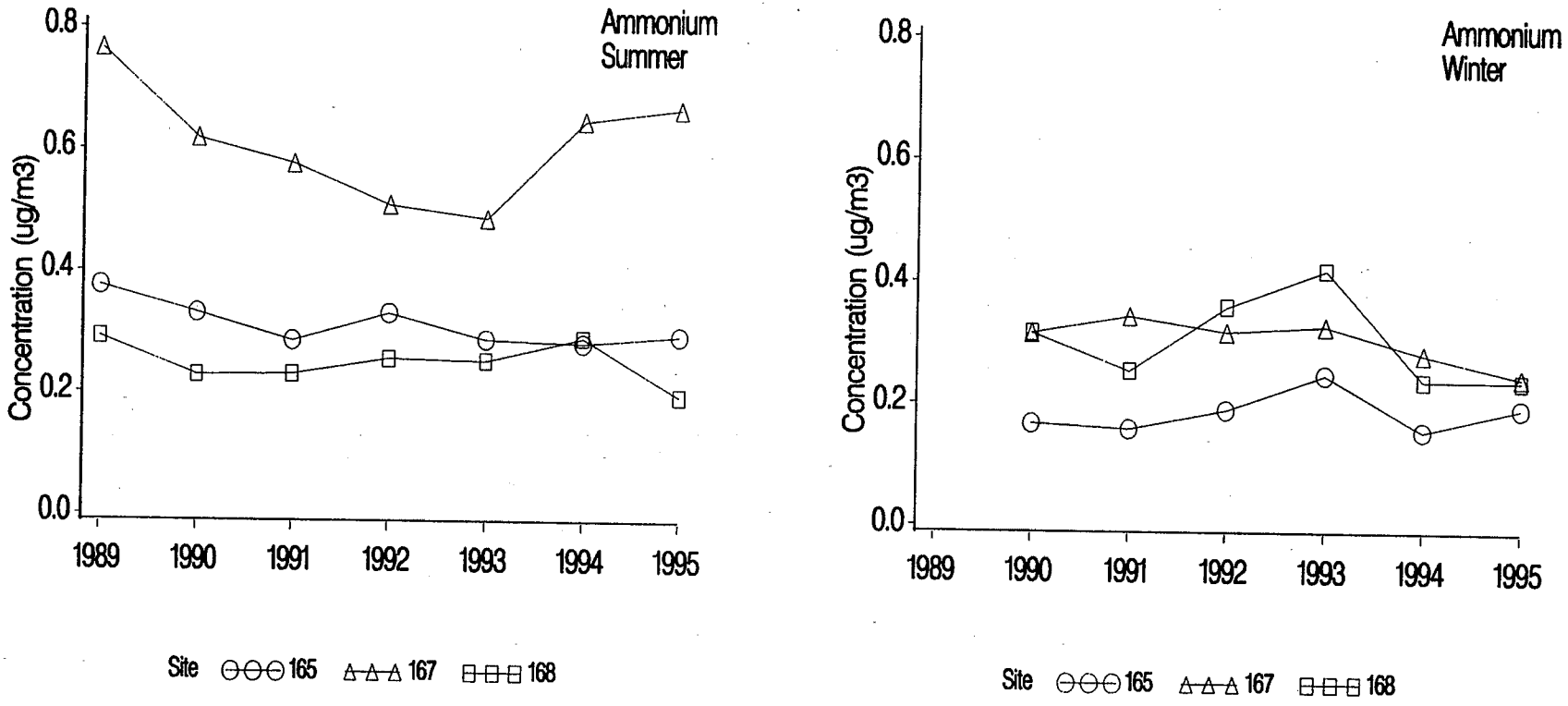


Figure 3-38. Seasonal (summer vs. winter) variability of NH_4^+ ($\mu g/m^3$) for three western sites

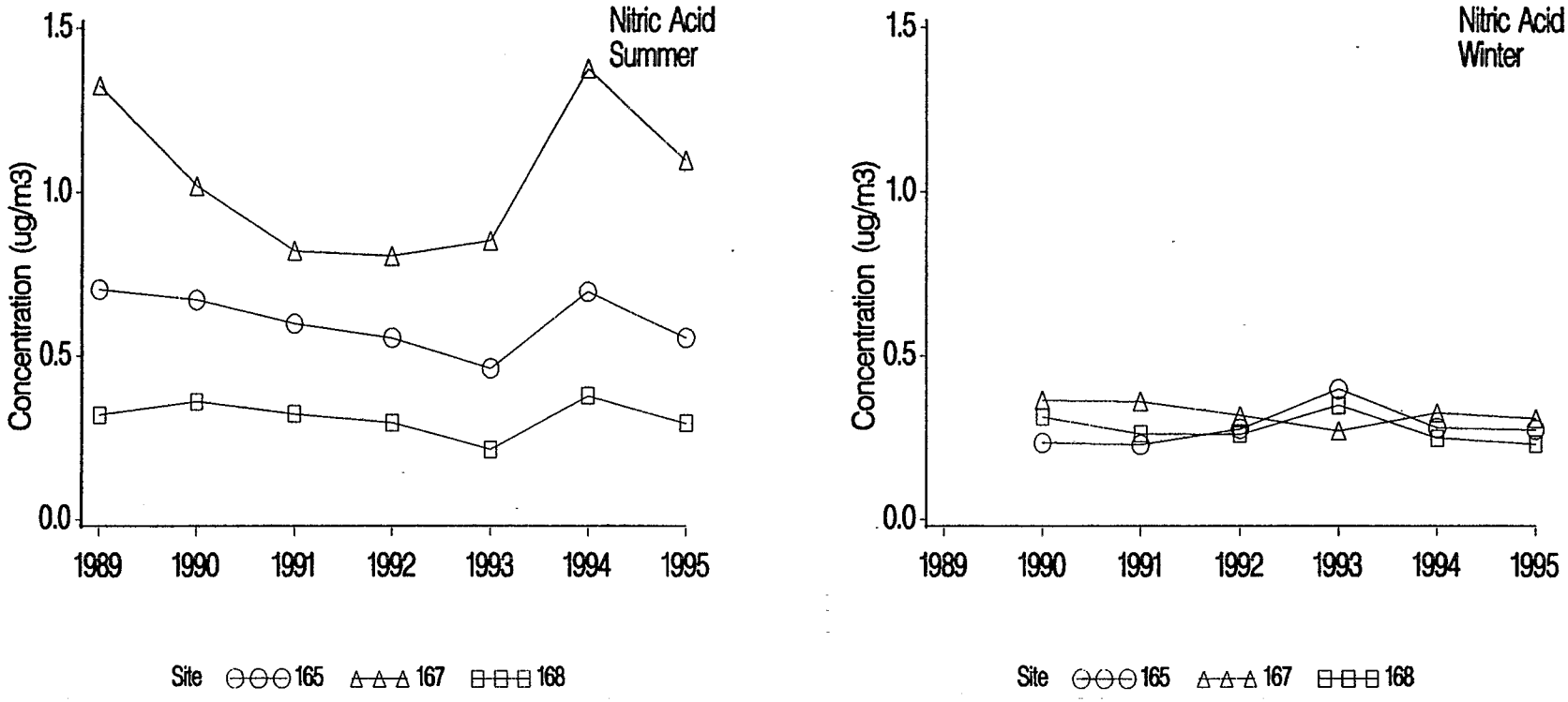


Figure 3-39. Seasonal (summer vs. winter) variability of HNO_3 ($\mu g/m^3$) for three western sites

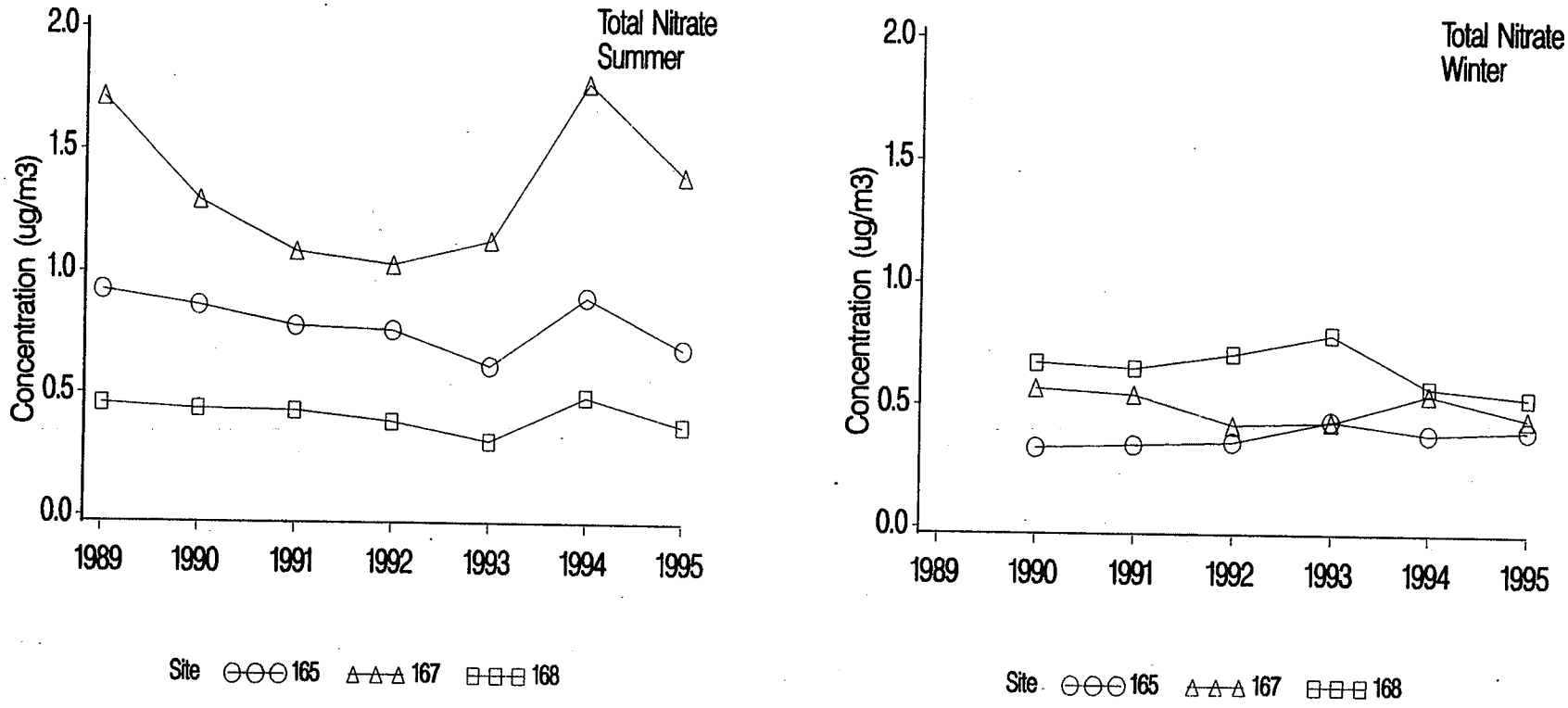


Figure 3-40. Seasonal (summer vs. winter) variability of total NO_3^- ($\mu g/m^3$) for three western sites

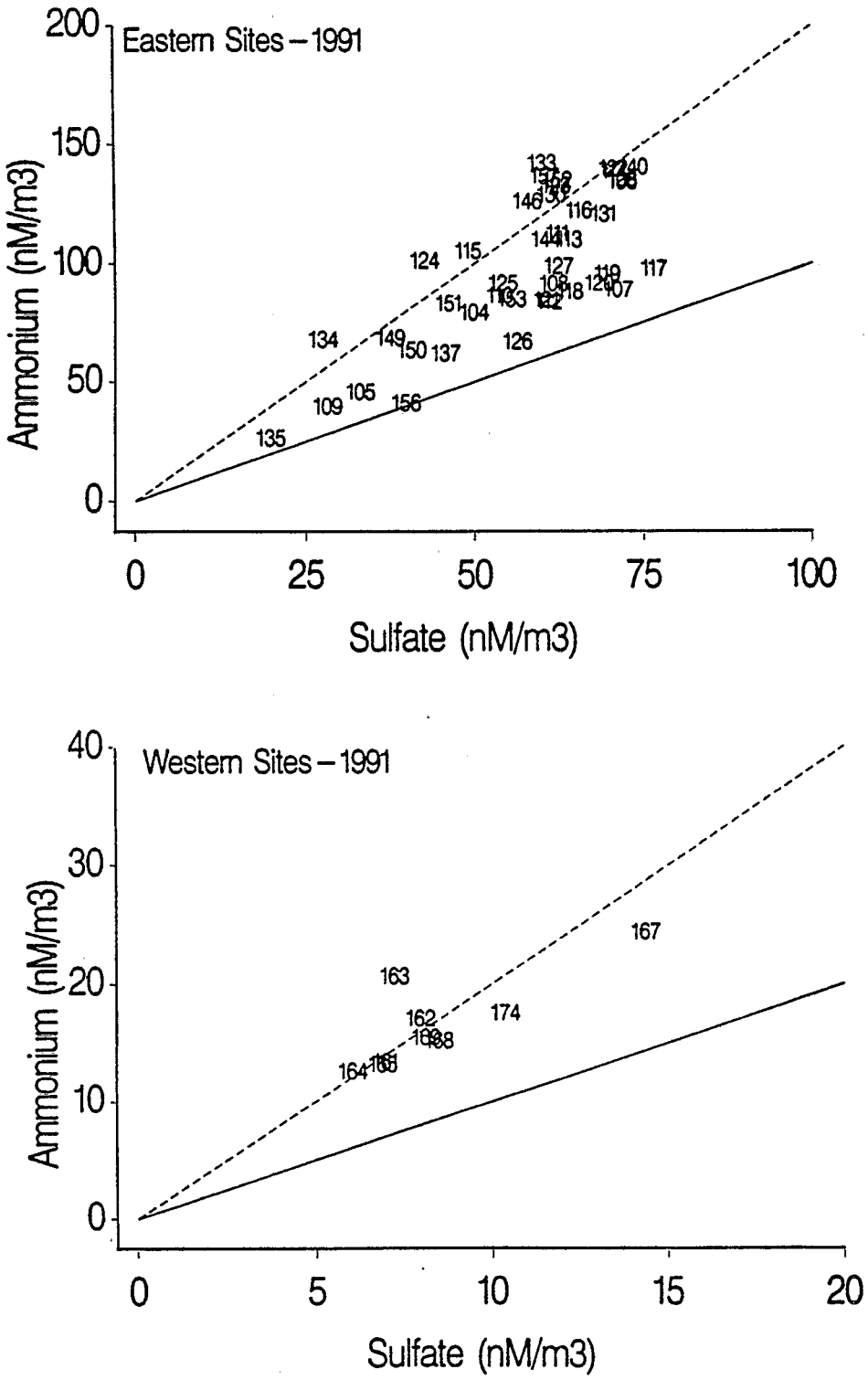


Figure 3-41. Scattergram of NH_4^+ versus SO_4^{2-} (molar basis) for 1991

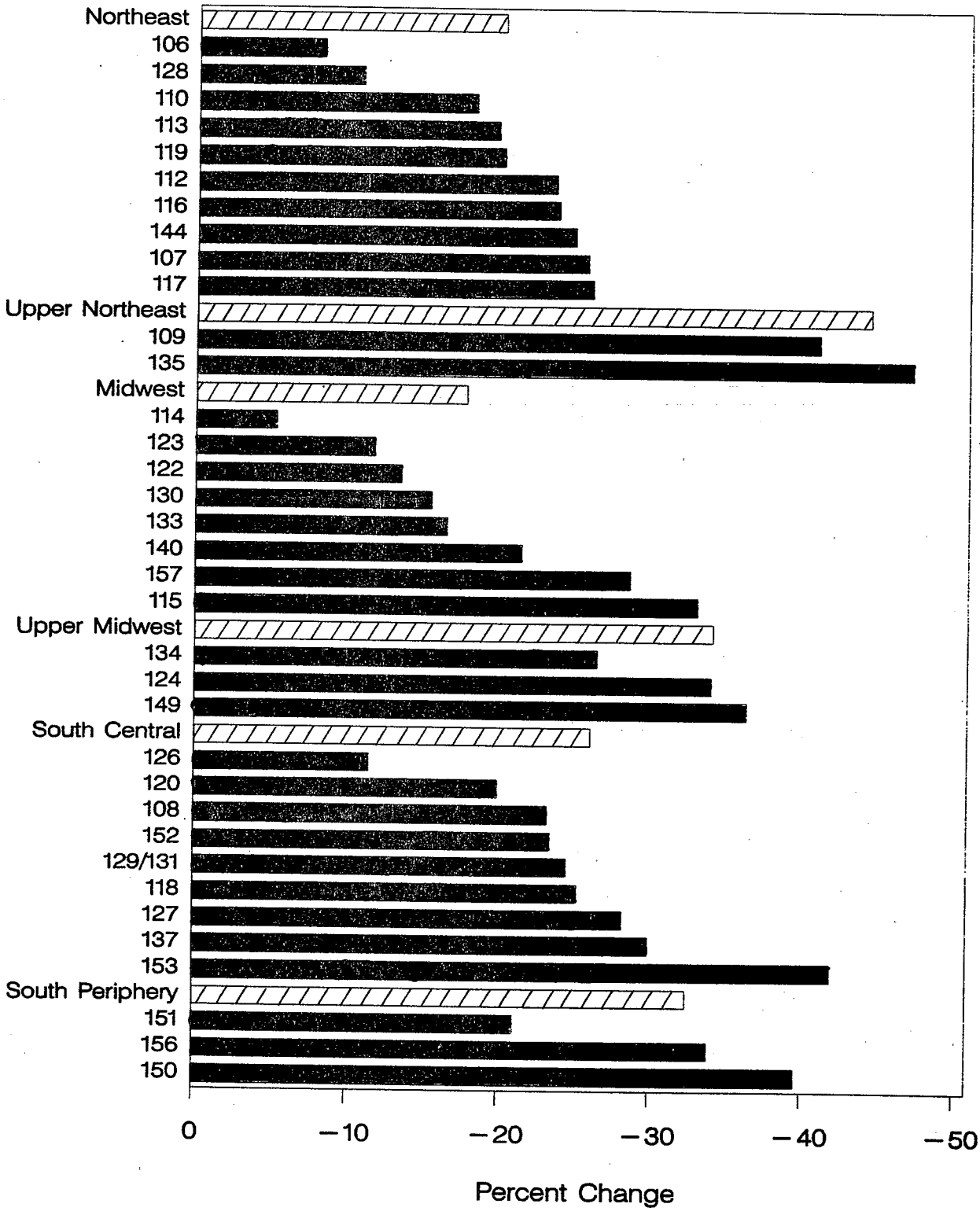


Figure 3-42. Change in SO_2 Concentrations from 1989 to 1995

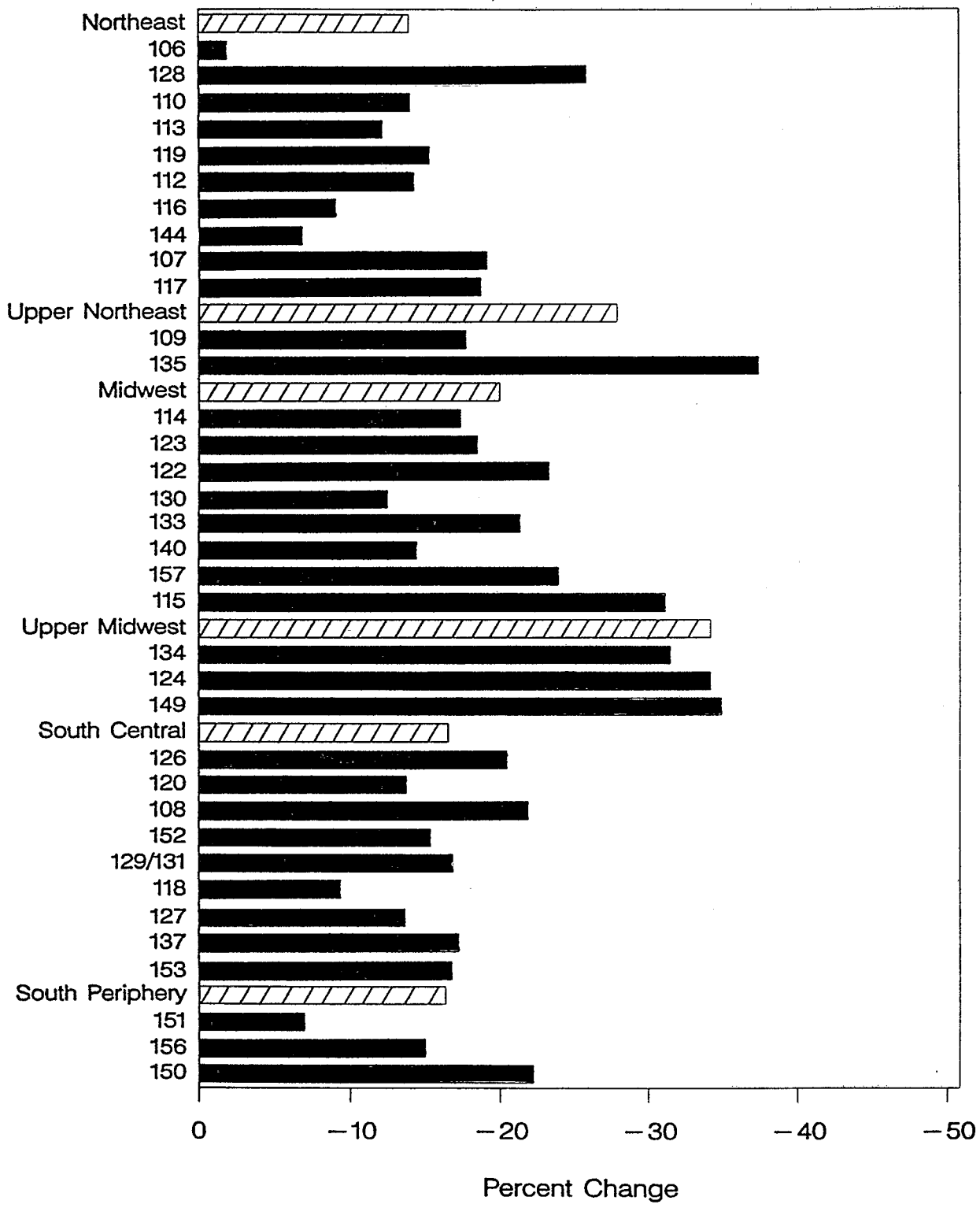


Figure 3-43. Change in SO_4^{2-} Concentrations from 1989 to 1995

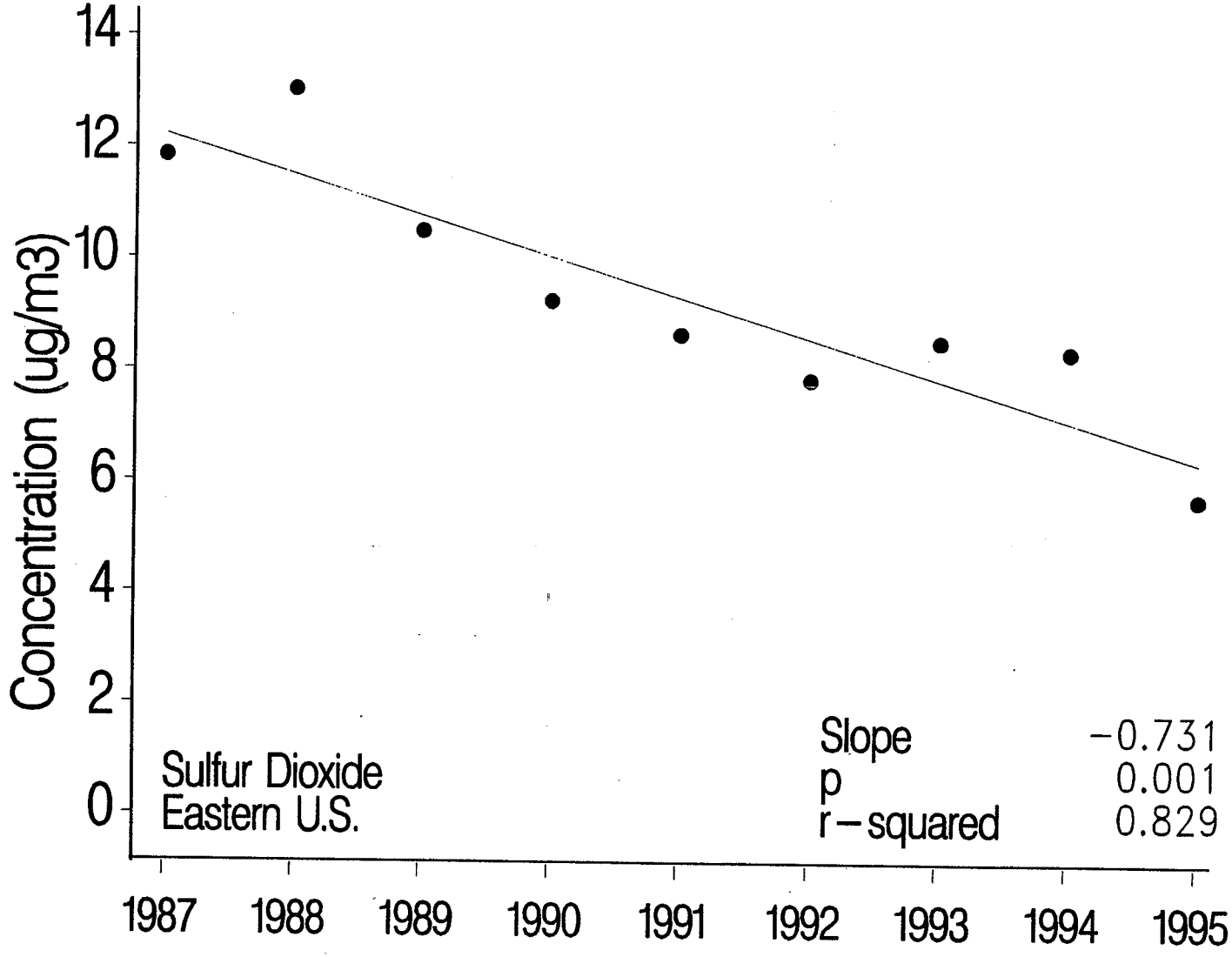


Figure 3-44. Linear regression analyses for annual SO_2 concentrations

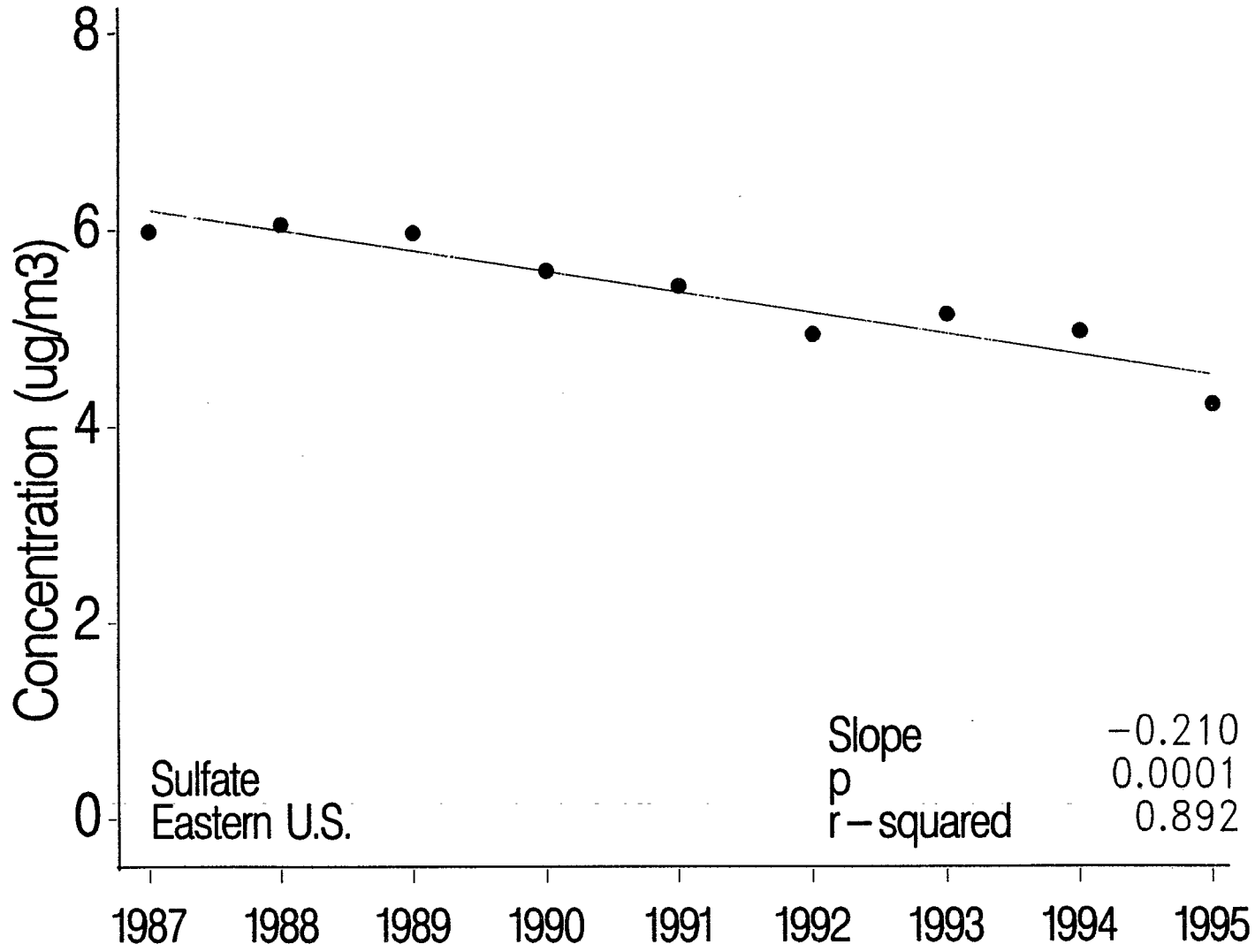


Figure 3-45. Linear regression analyses for annual SO_4^{2-} concentrations

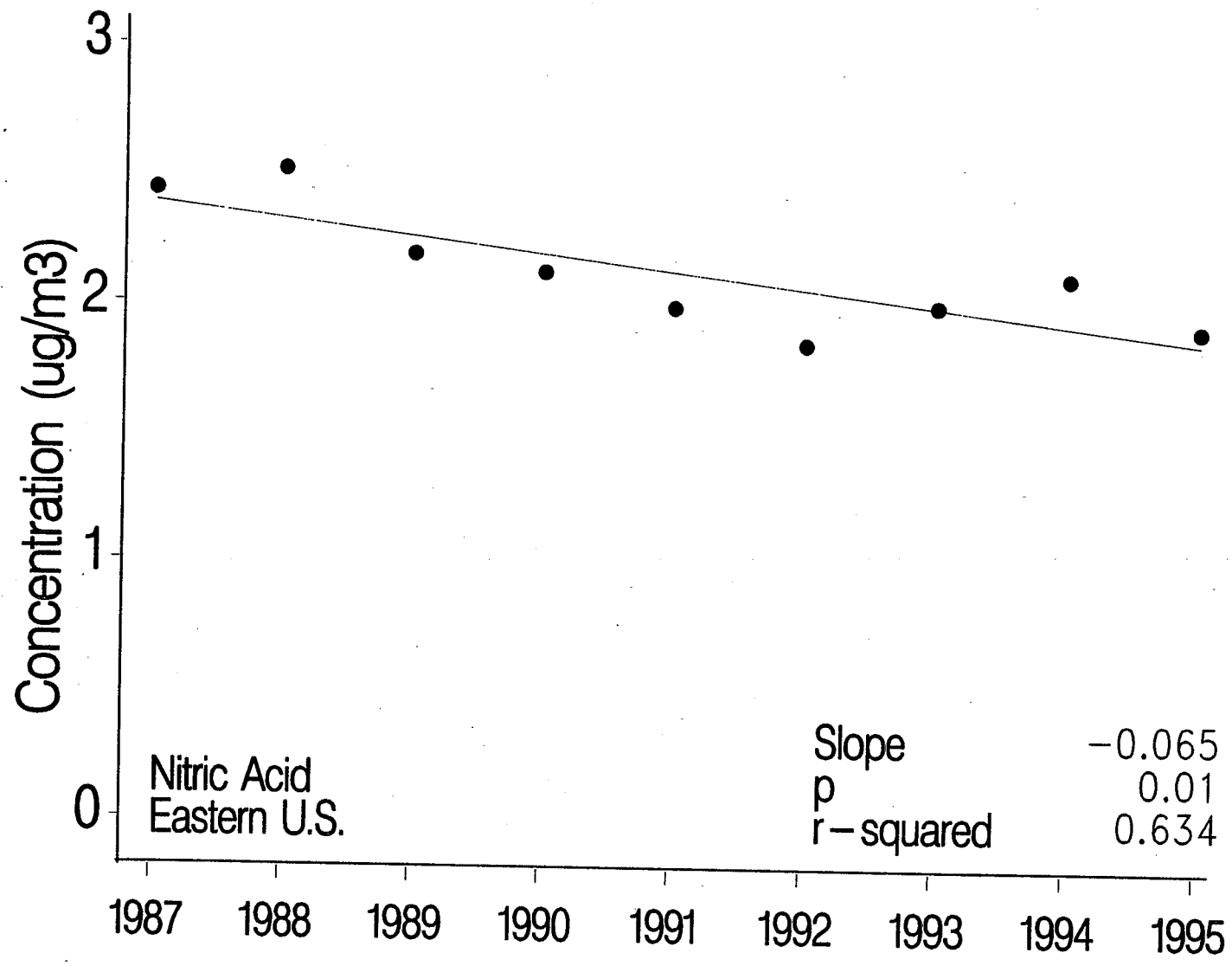


Figure 3-46. Linear regression analyses for annual HNO_3 concentrations

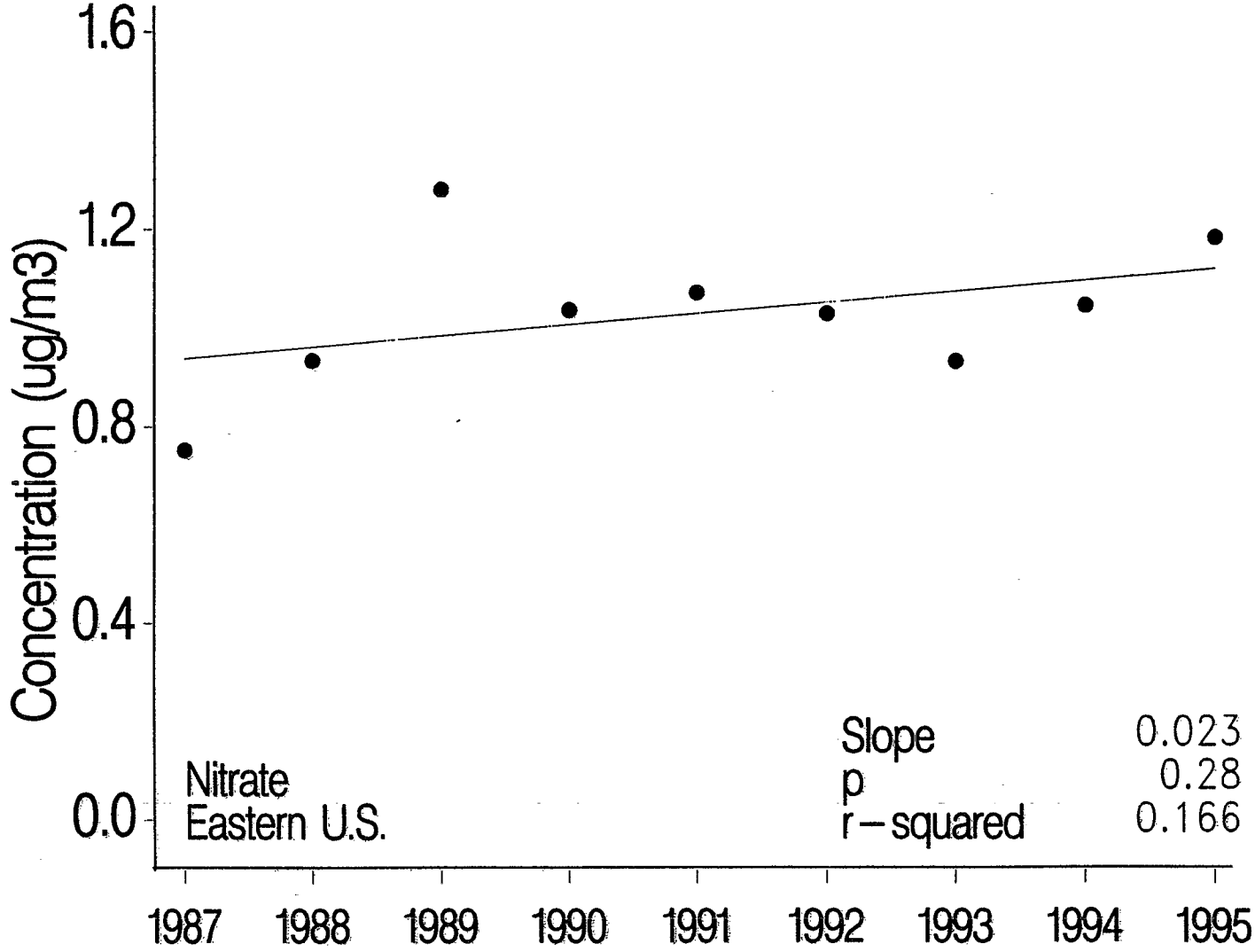


Figure 3-47. Linear regression analyses for annual NO_3 concentrations

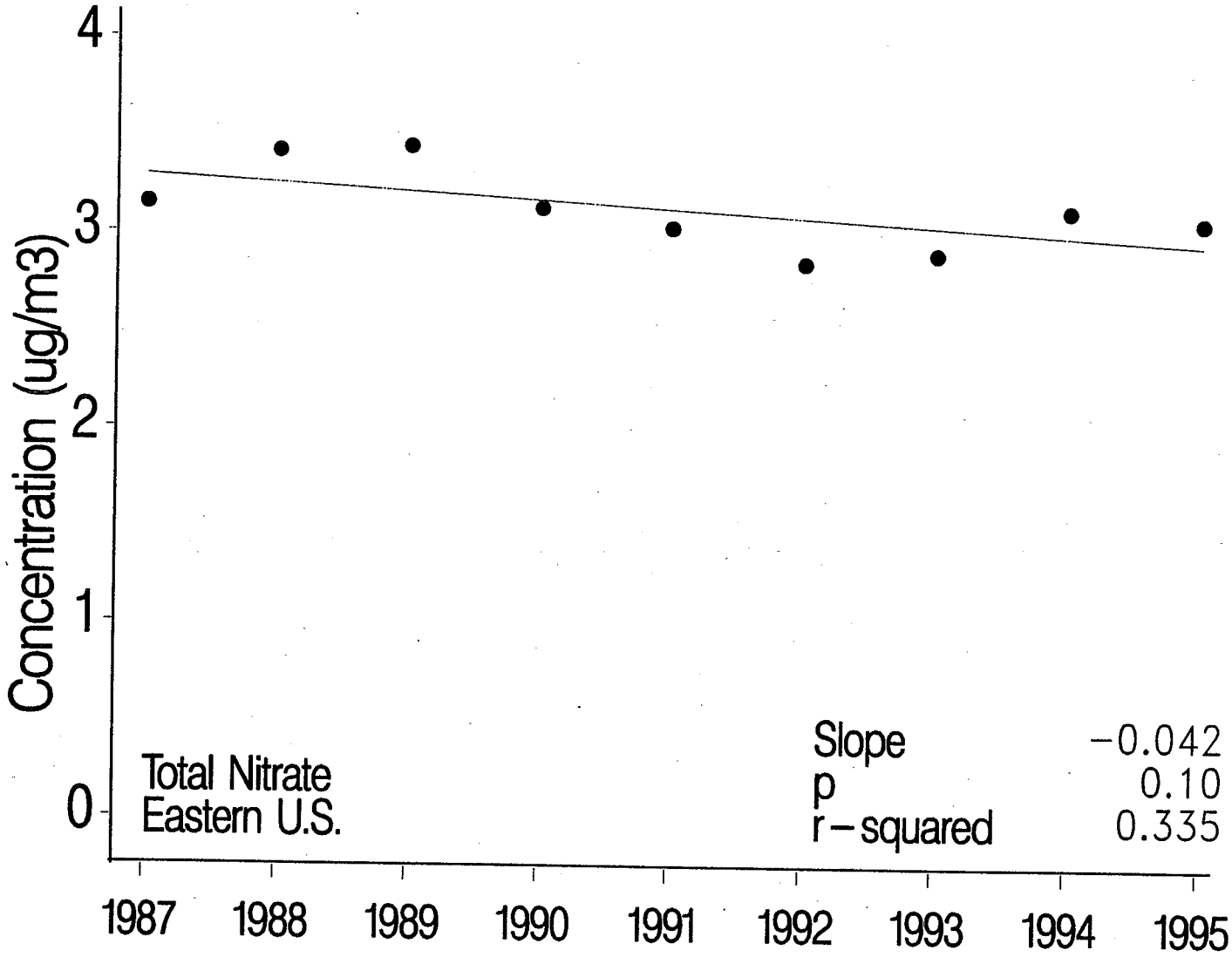


Figure 3-48. Linear regression analyses for annual total NO_3^- concentrations

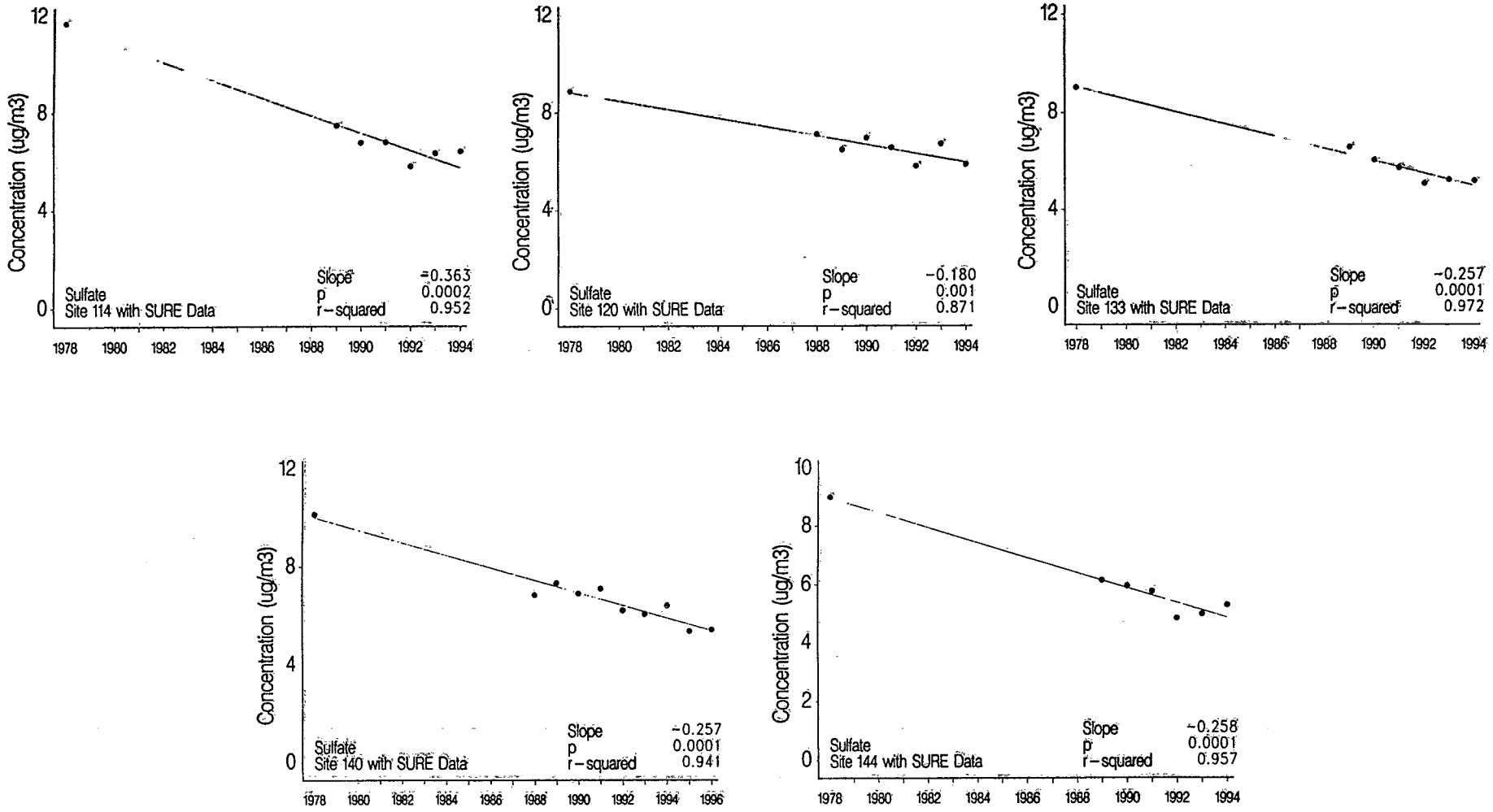
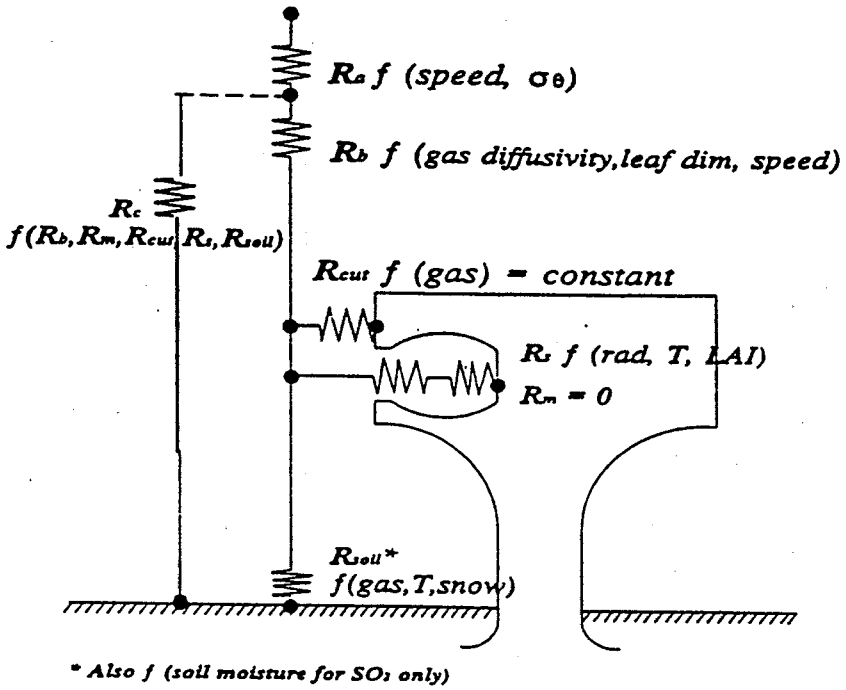


Figure 3-49. Linear regression analyses for five sites using SURE and CASTNet data (1978 through 1994)



Where:

Flux = flux of chemical
C = concentration
V_d = deposition velocity
R_a = aerodynamic resistance
R_b = boundary layer resistance
R_c = bulk surface uptake resistance
R_{cut} = cuticular resistance
R_m = mesophyll resistance
R_s = stomatal resistance
R_{soil} = soil resistance
T = temperature
rad = solar radiation
speed = wind speed
σ_θ = standard deviation of wind direction
snow = snow absence/presence
LAI = leaf area index

SOURCE: EPA, 1997.

Figure 3-50. The Multilayer inferential model

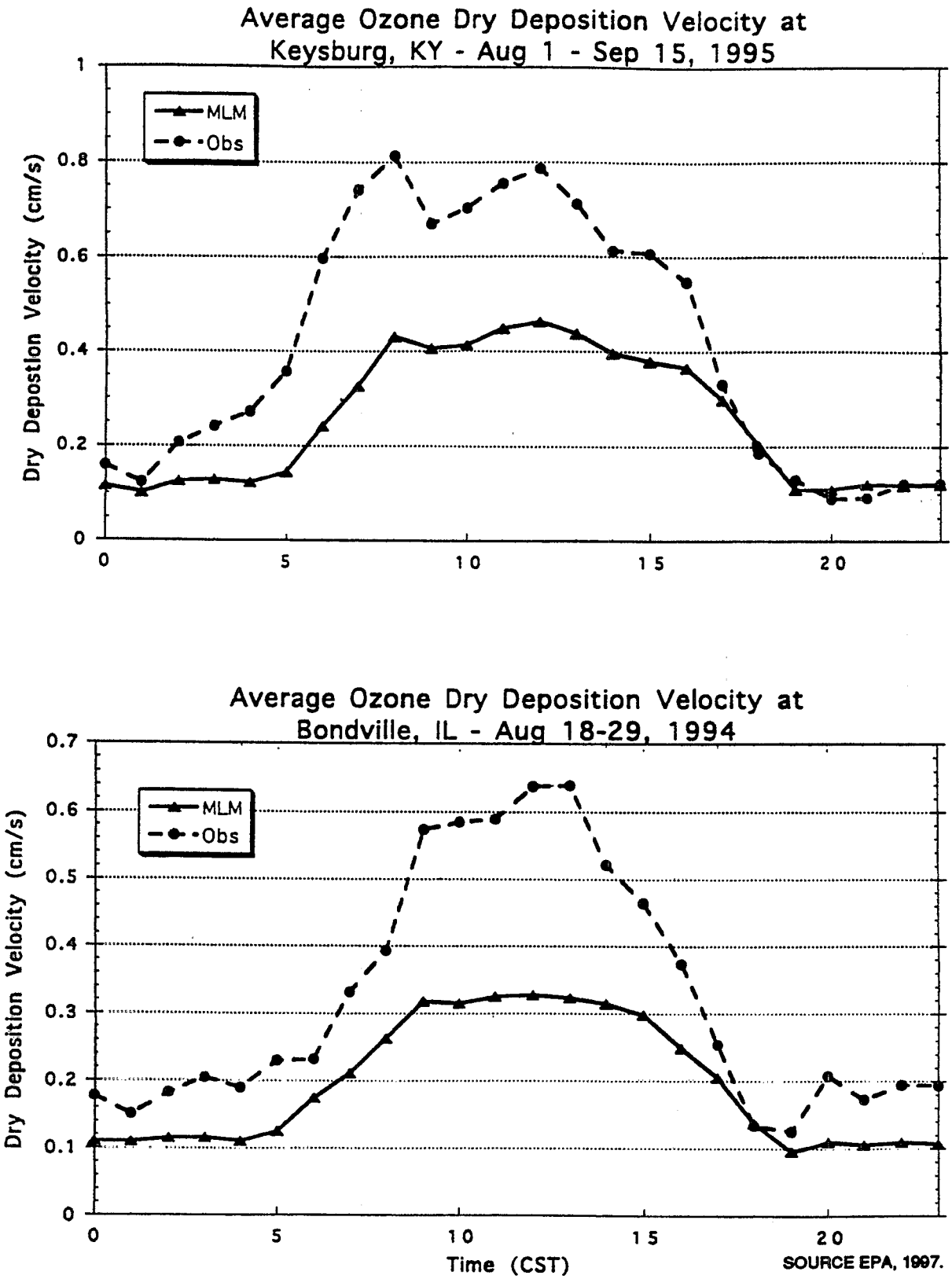


Figure 3-51. Comparison of MLM simulations and field measurements of V_d for O_3 at Bondville and Keysburg

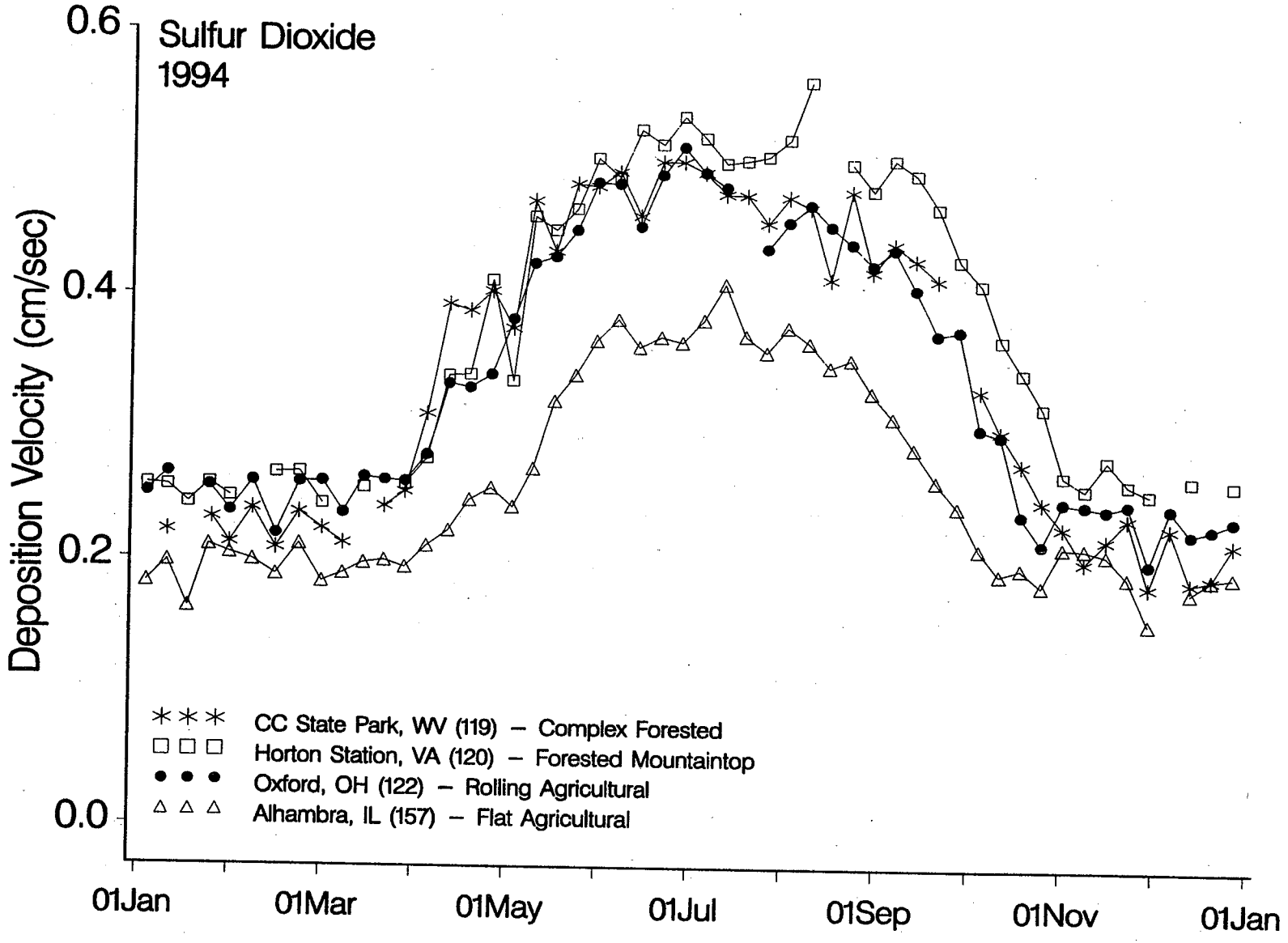


Figure 3-52. Weekly SO_2 deposition velocities for four eastern sites (1994)

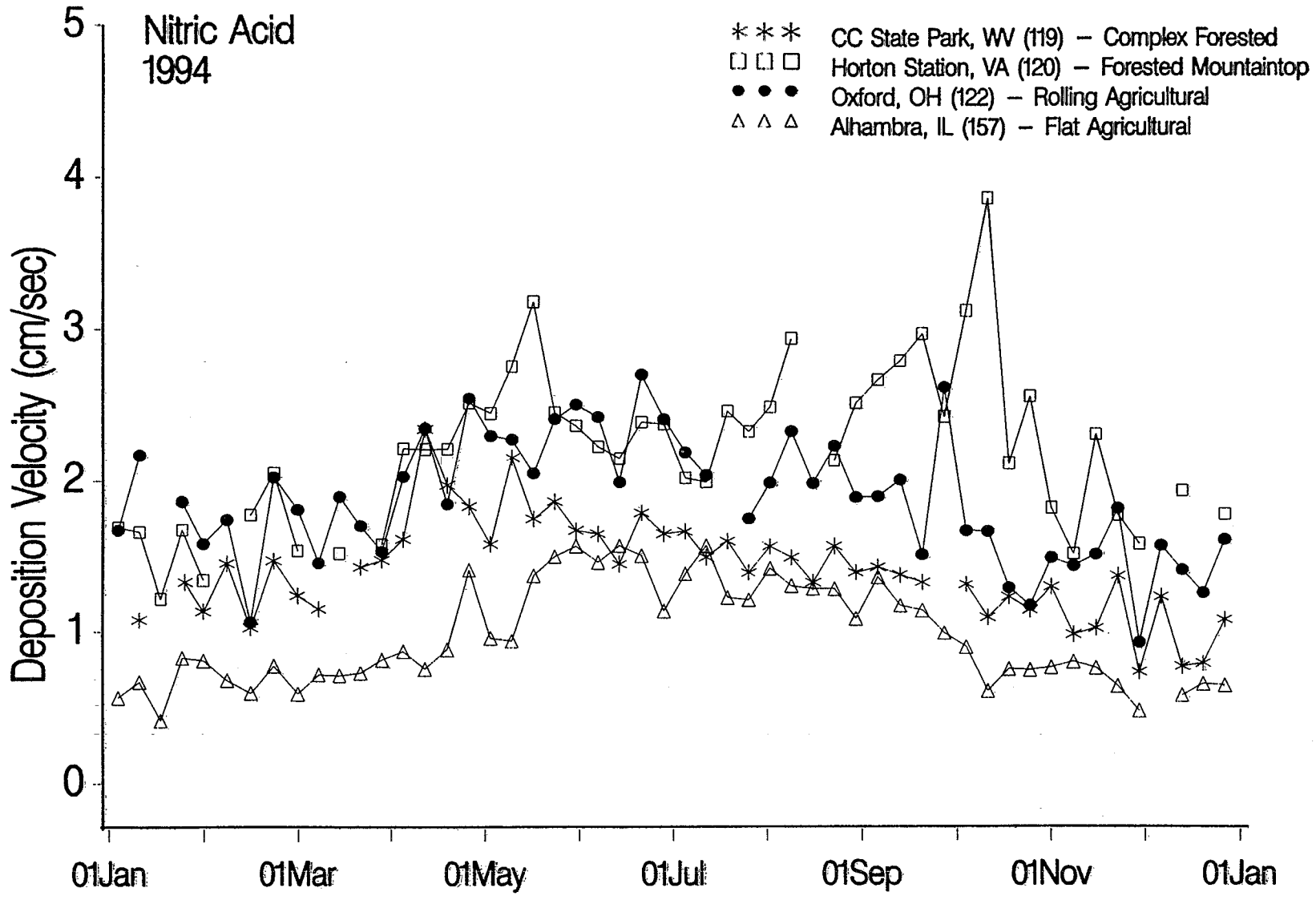


Figure 3-53. Weekly HNO_3 deposition velocities for four eastern sites (1994)

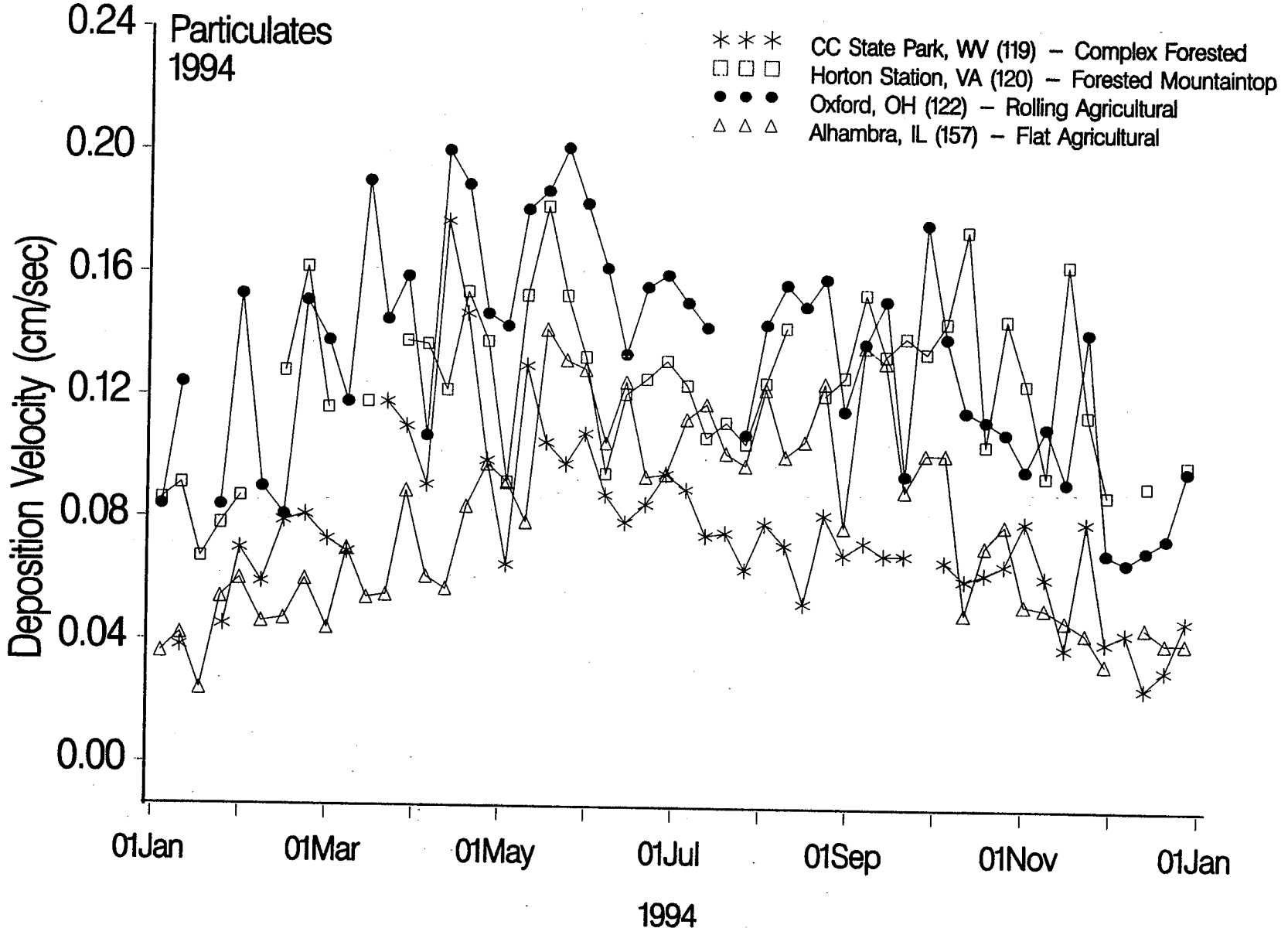


Figure 3-54. Weekly particulate deposition velocities for four eastern sites (1994)

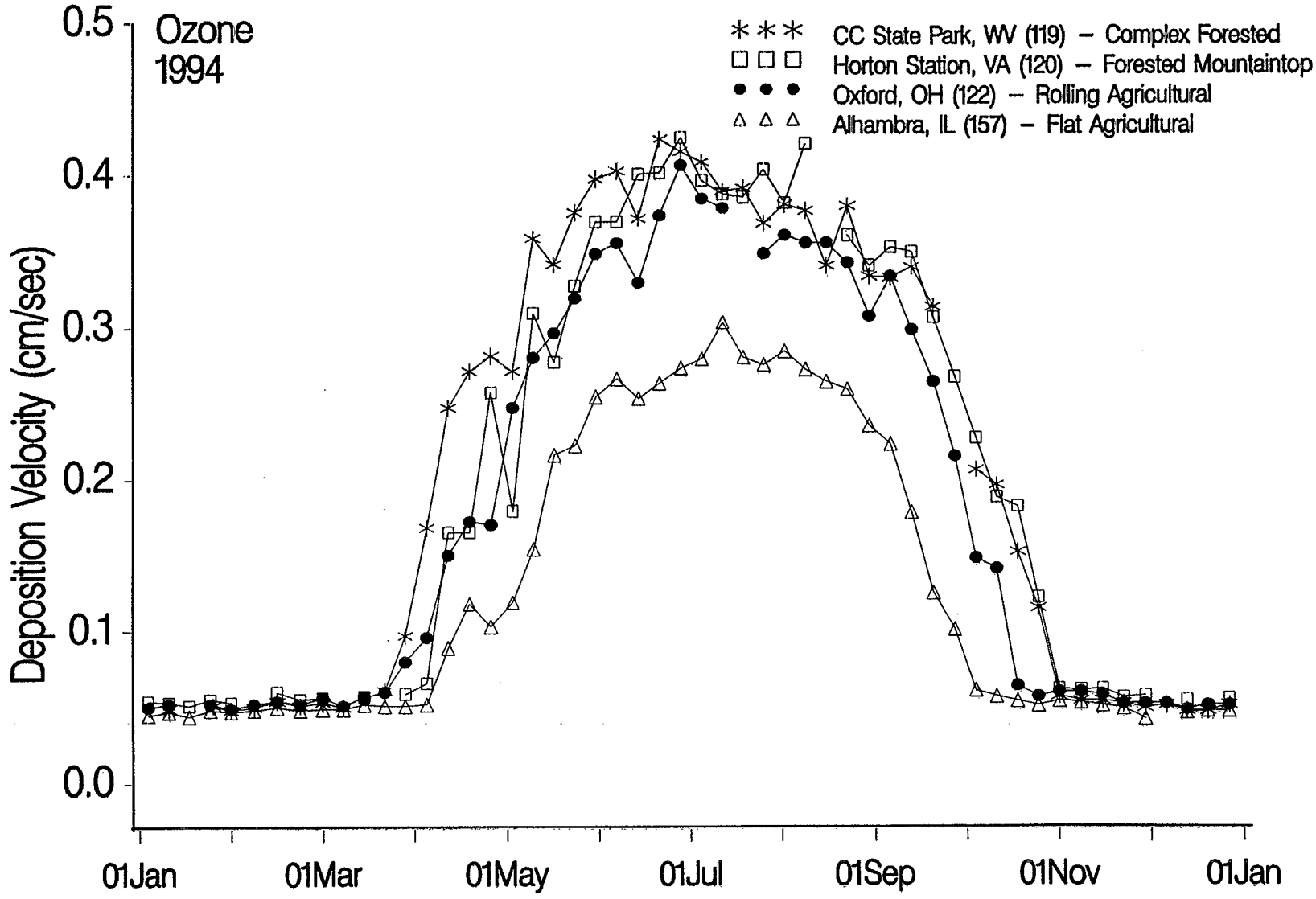


Figure 3-55. Weekly O_3 deposition velocities for four eastern sites (1994)

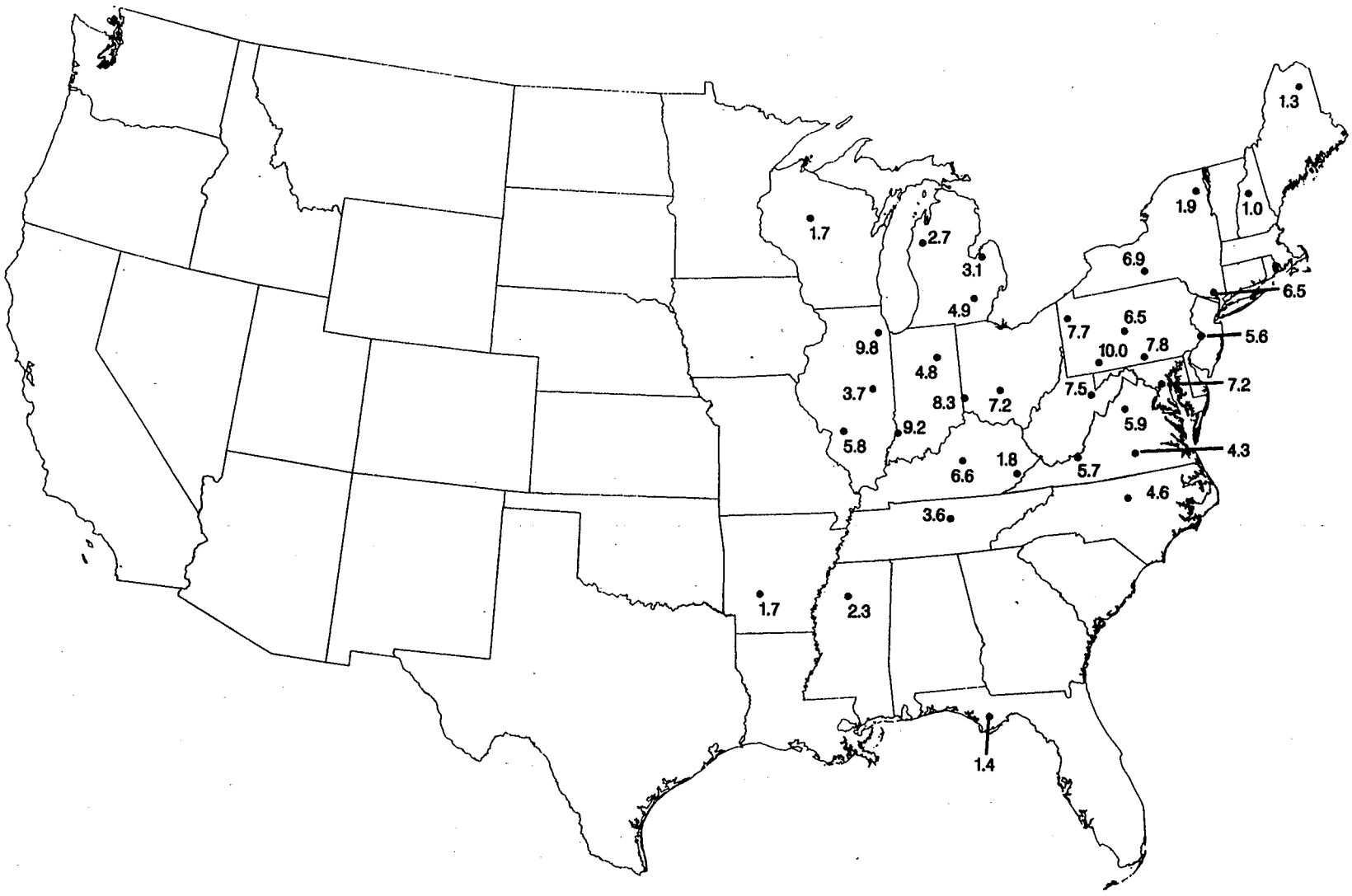


Figure 3-56. Mean annual dry fluxes of total sulfur for 1989

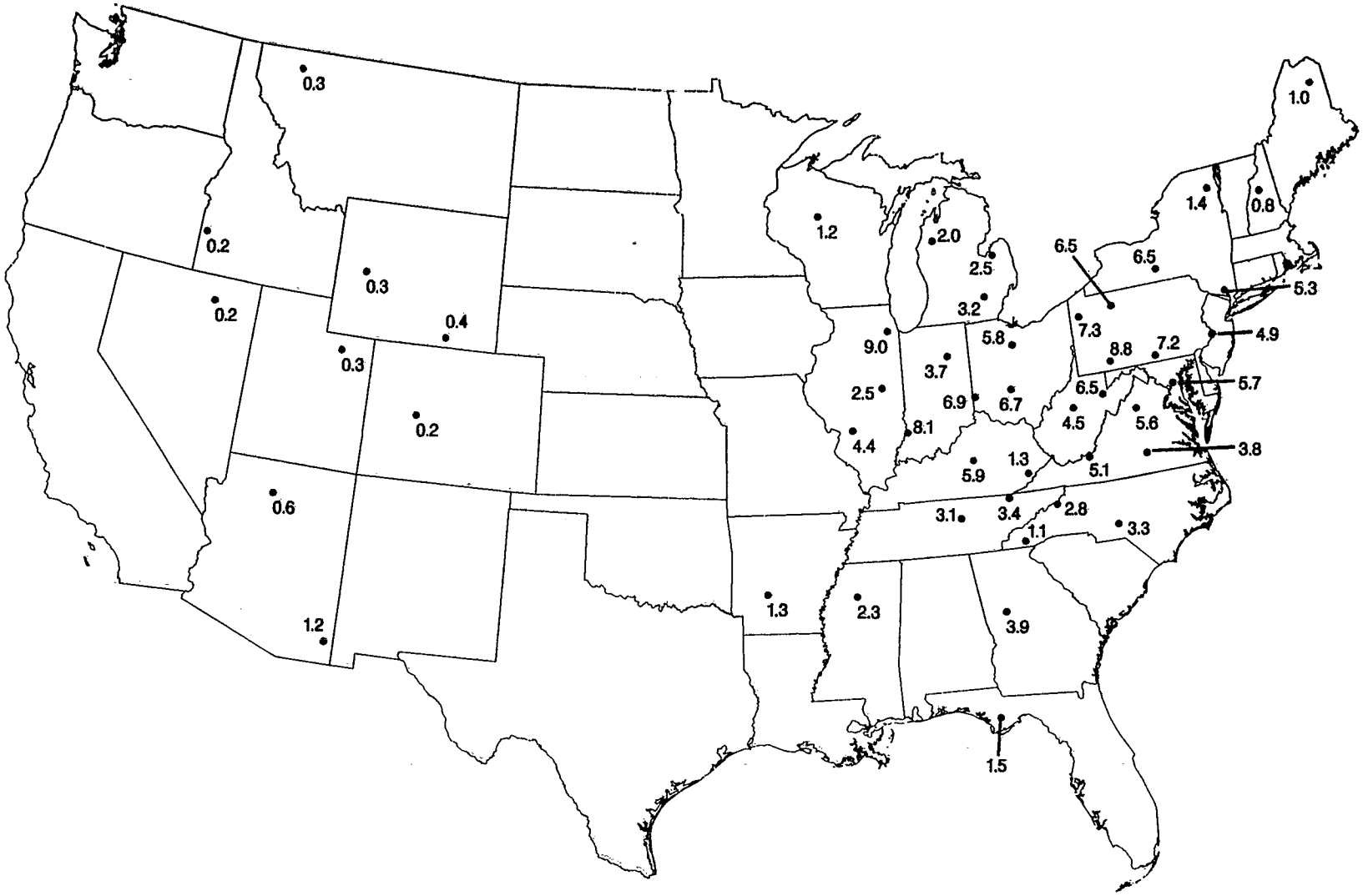


Figure 3-57. Mean annual dry fluxes of total sulfur for 1992

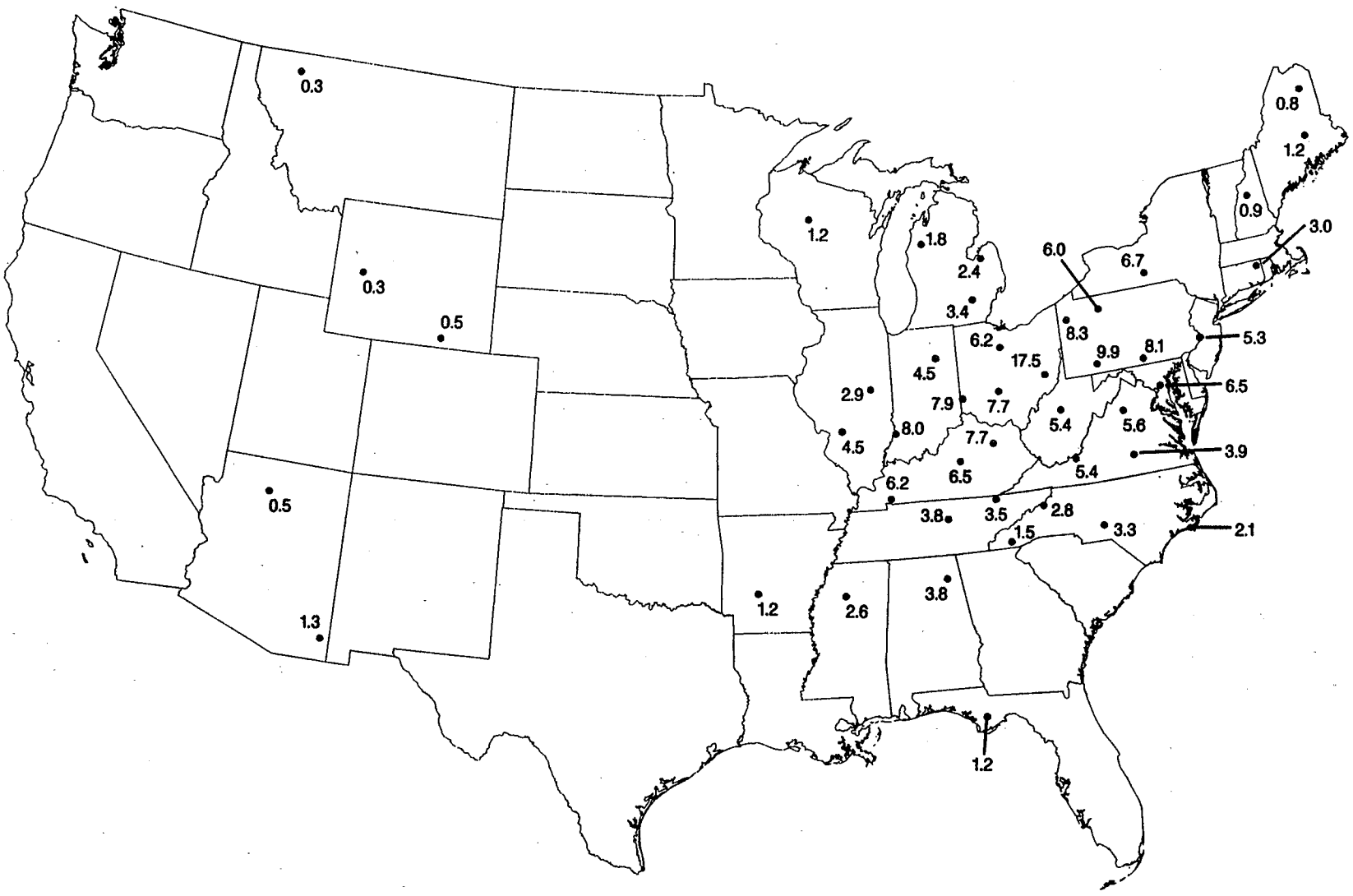


Figure 3-58. Mean annual dry fluxes of total sulfur for 1994

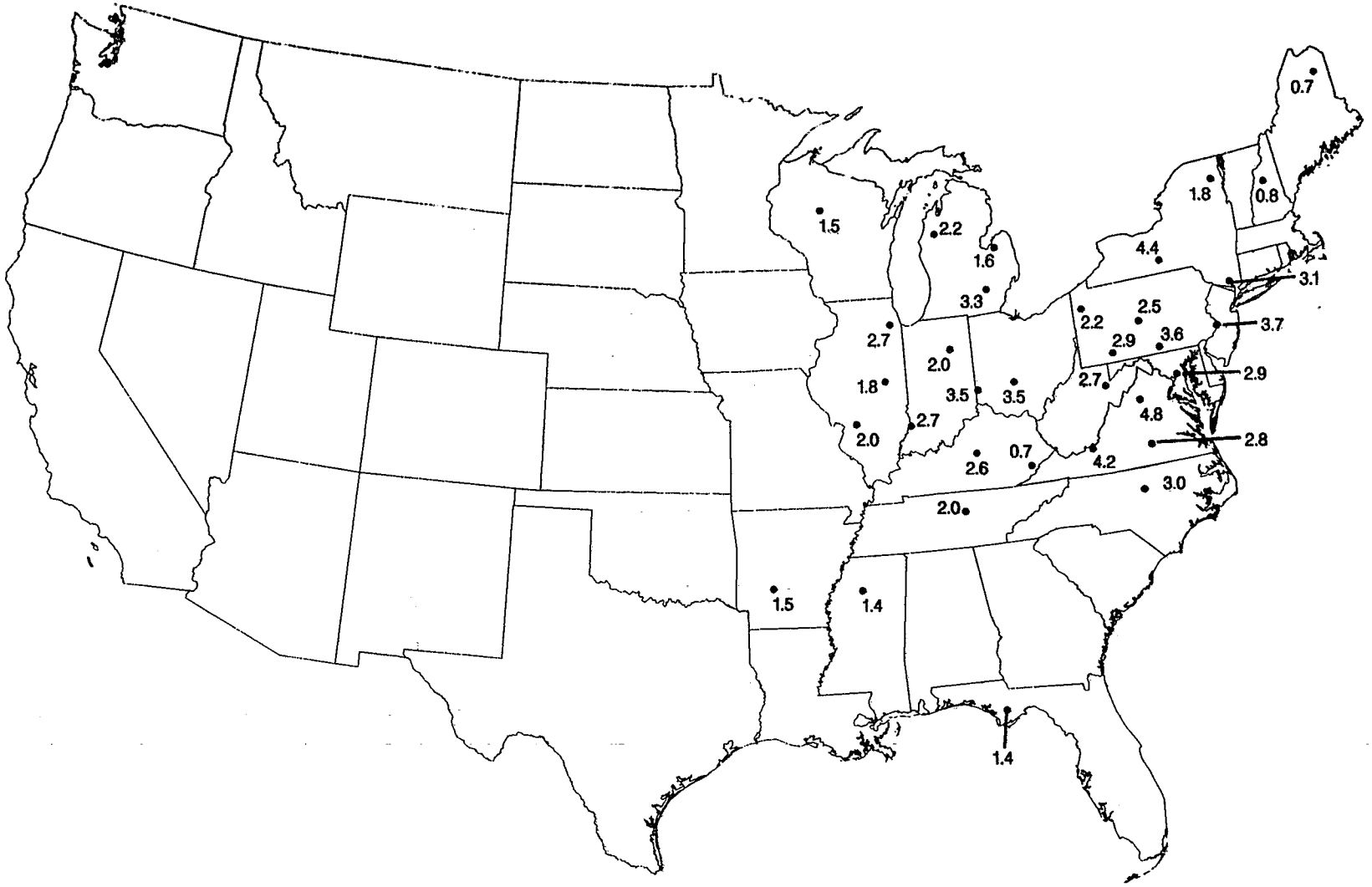


Figure 3-59. Mean annual dry fluxes of total nitrogen for 1989

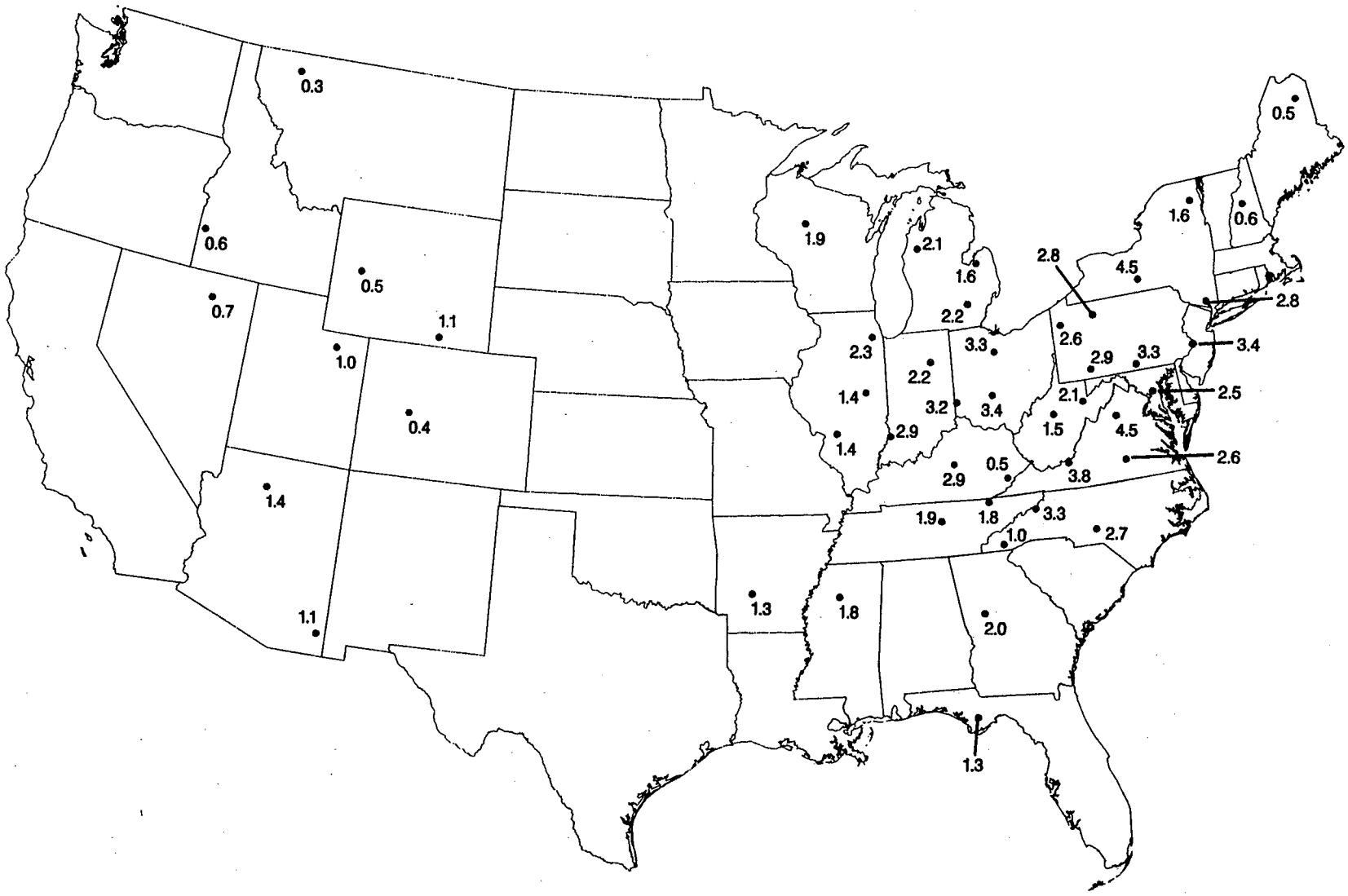


Figure 3-60. Mean annual dry fluxes of total nitrogen for 1992

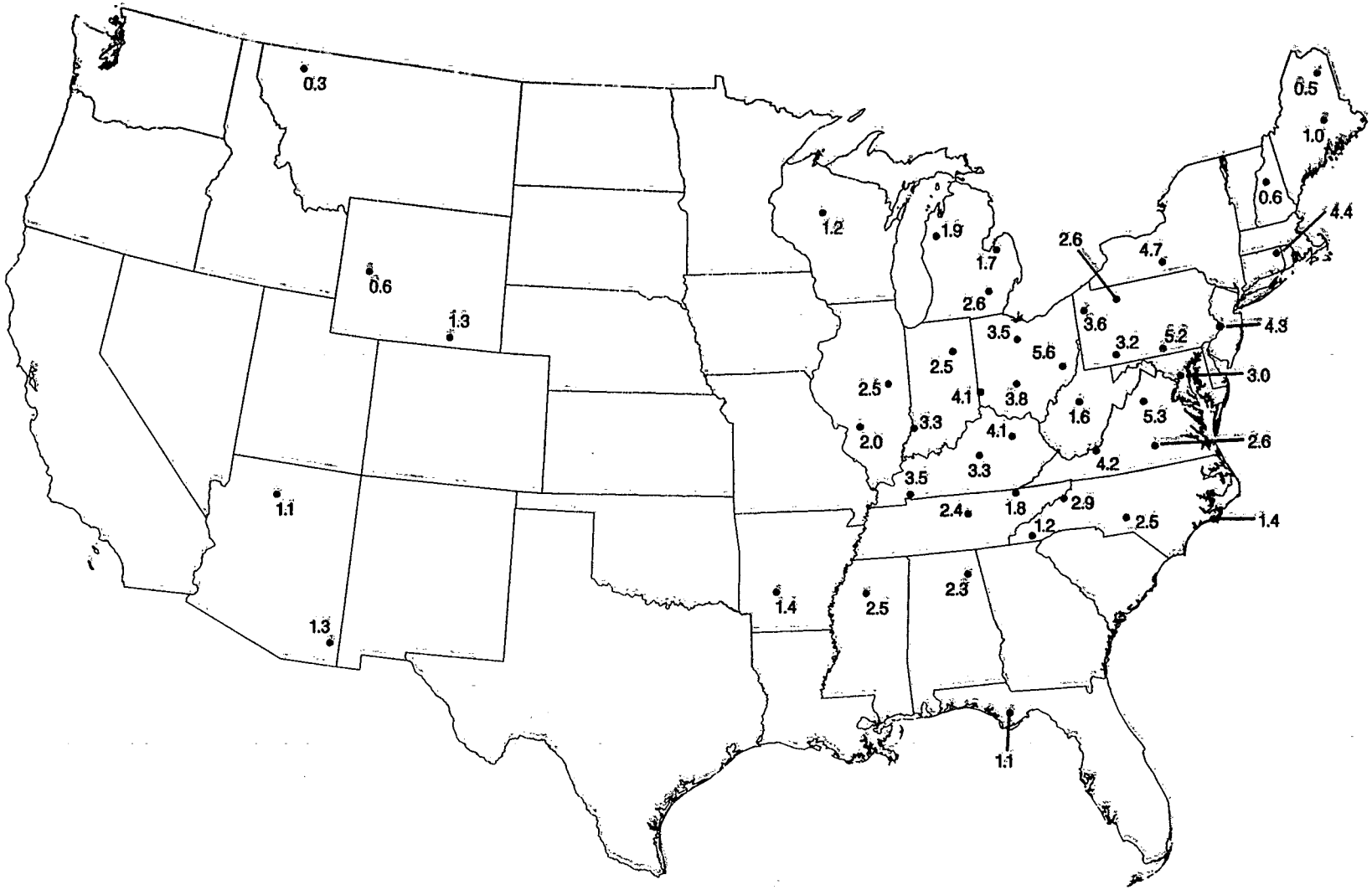


Figure 3-61. Mean annual dry fluxes of total nitrogen for 1994

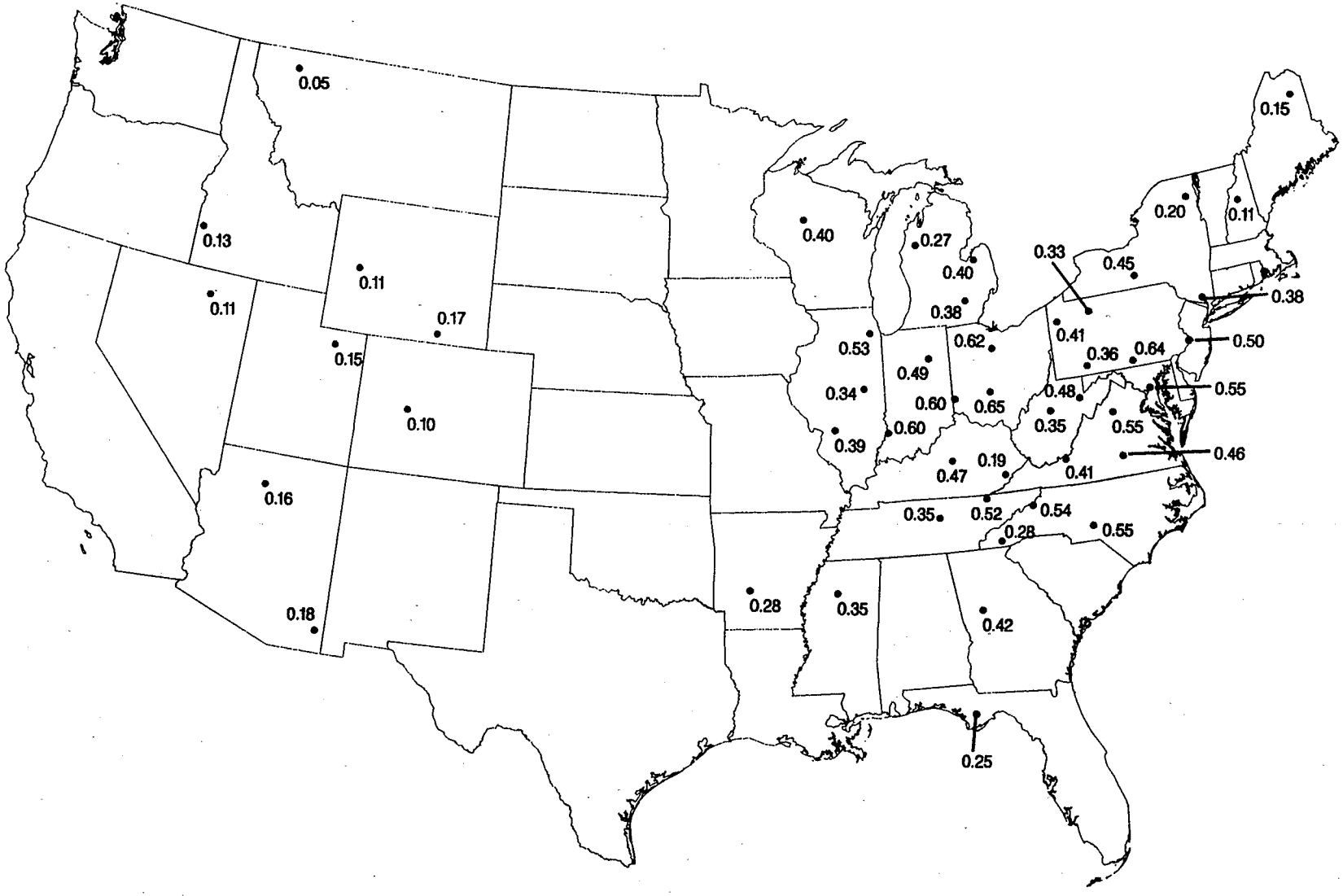


Figure 3-62. Mean annual dry fluxes of NH_4^+ for 1992

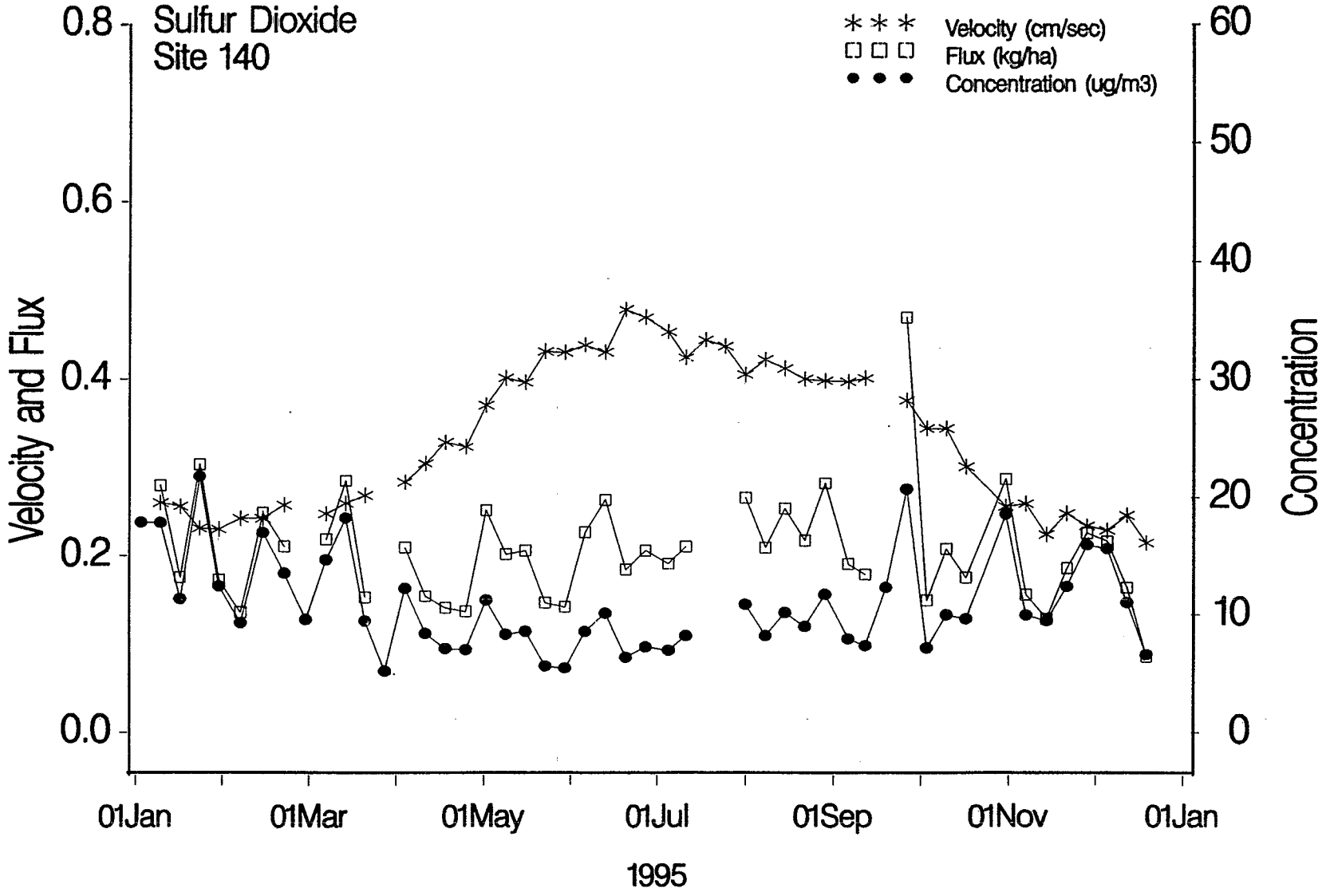


Figure 3-63. Weekly SO_2 concentrations, deposition velocities, and fluxes for Site 140 (1995)

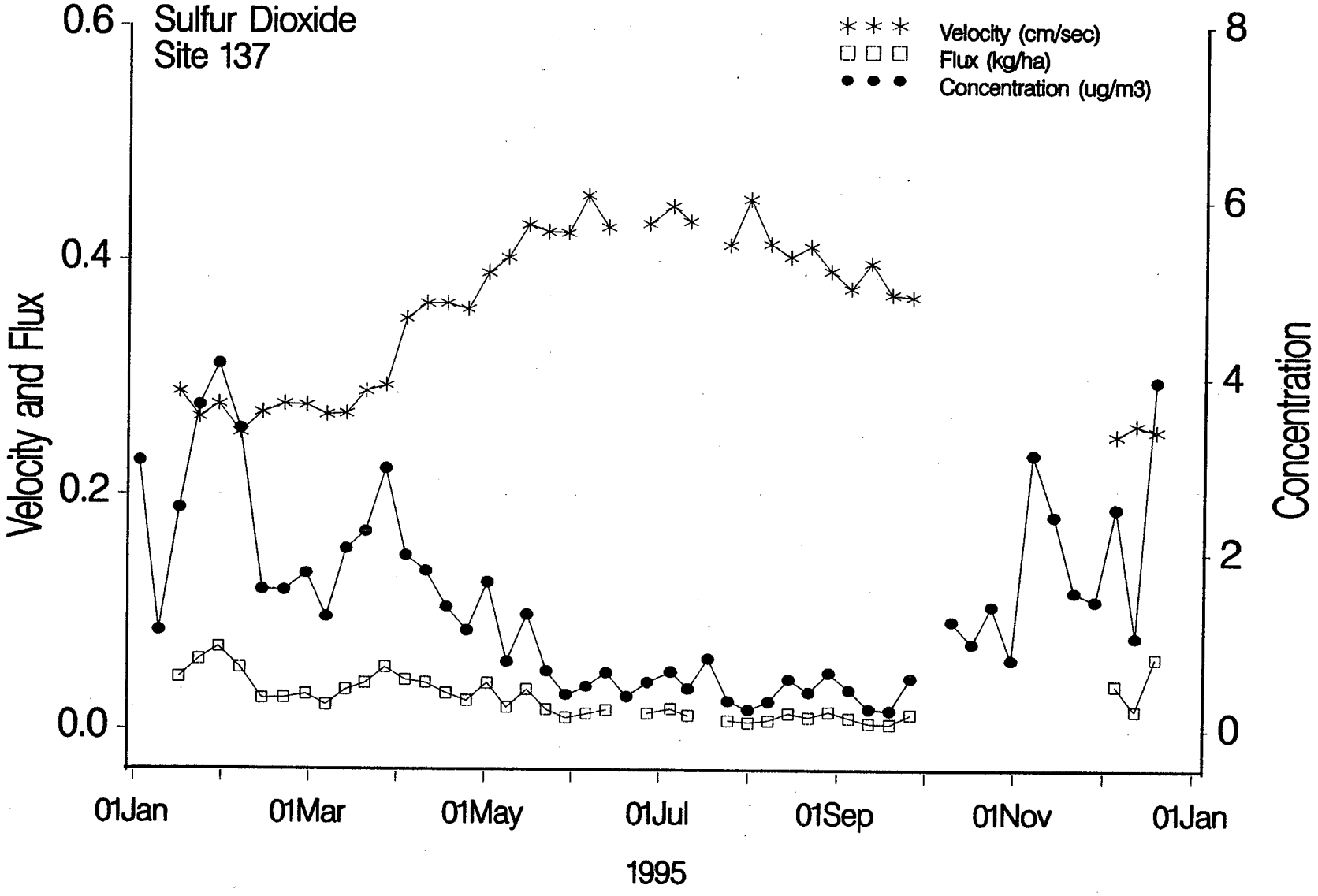


Figure 3-64. Weekly SO_2 concentrations, deposition velocities, and fluxes for Site 137 (1995)

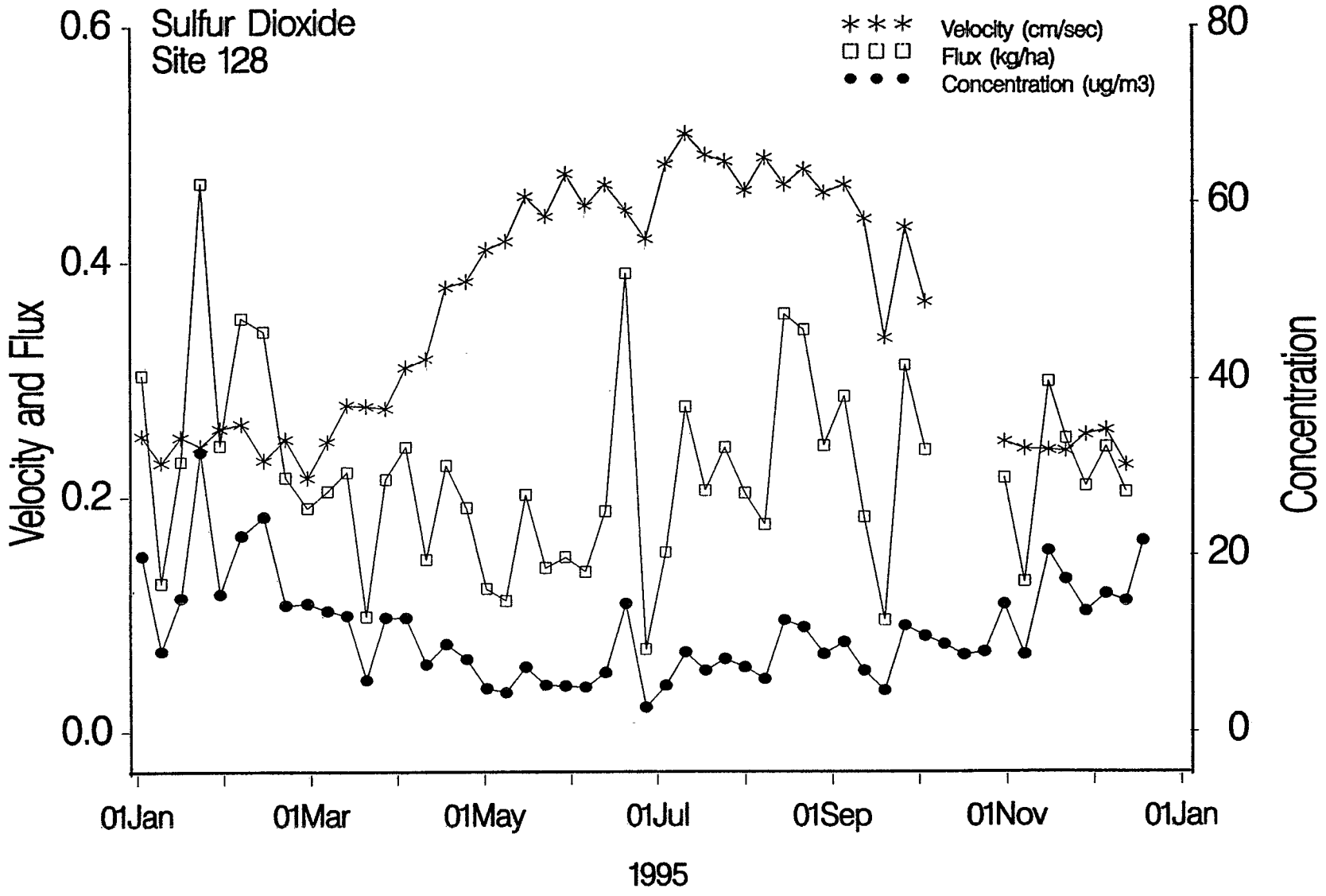


Figure 3-65. Weekly SO_2 concentrations, deposition velocities, and fluxes for Site 128 (1995)

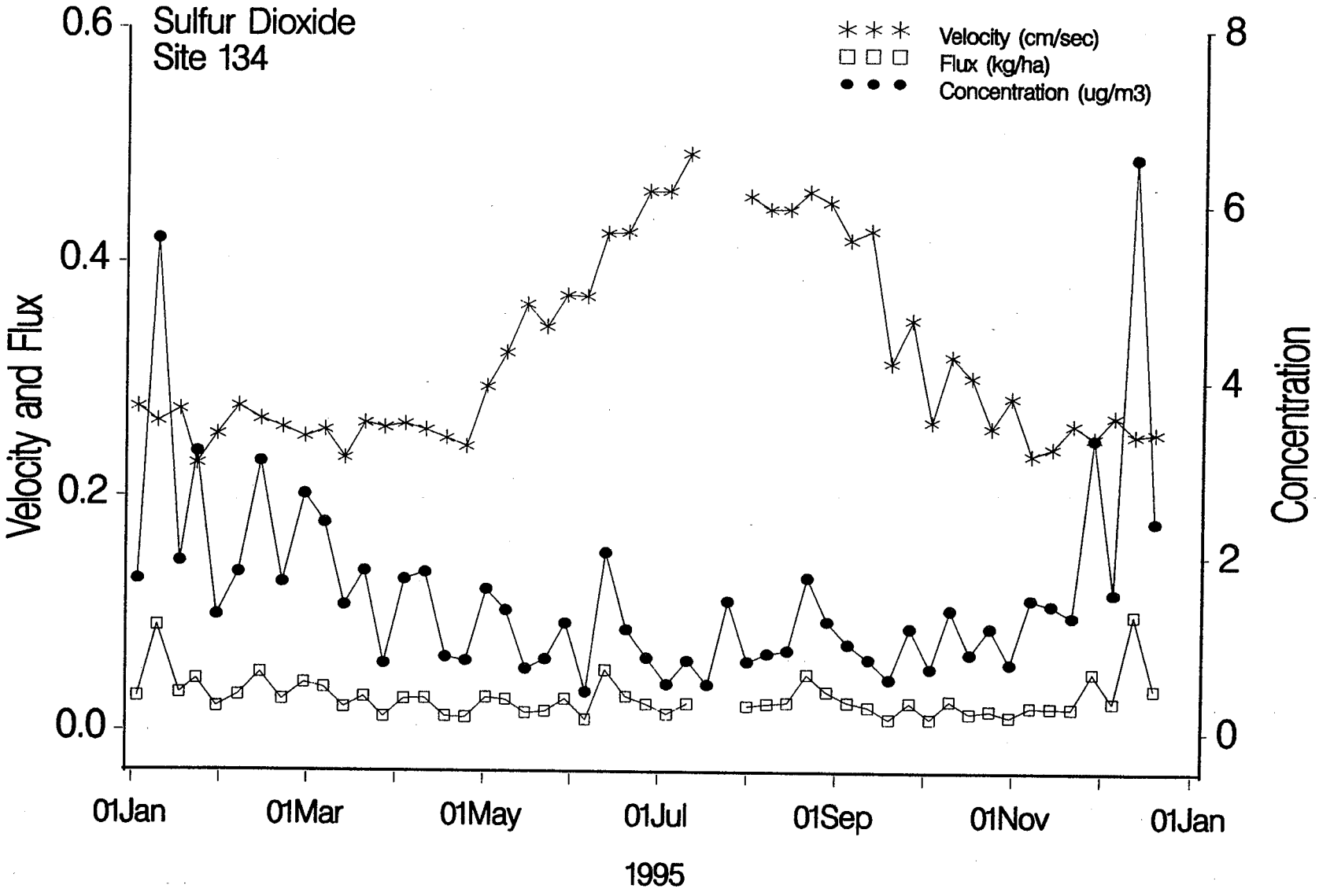


Figure 3-66. Weekly SO_2 concentrations, deposition velocities, and fluxes for Site 134 (1995)

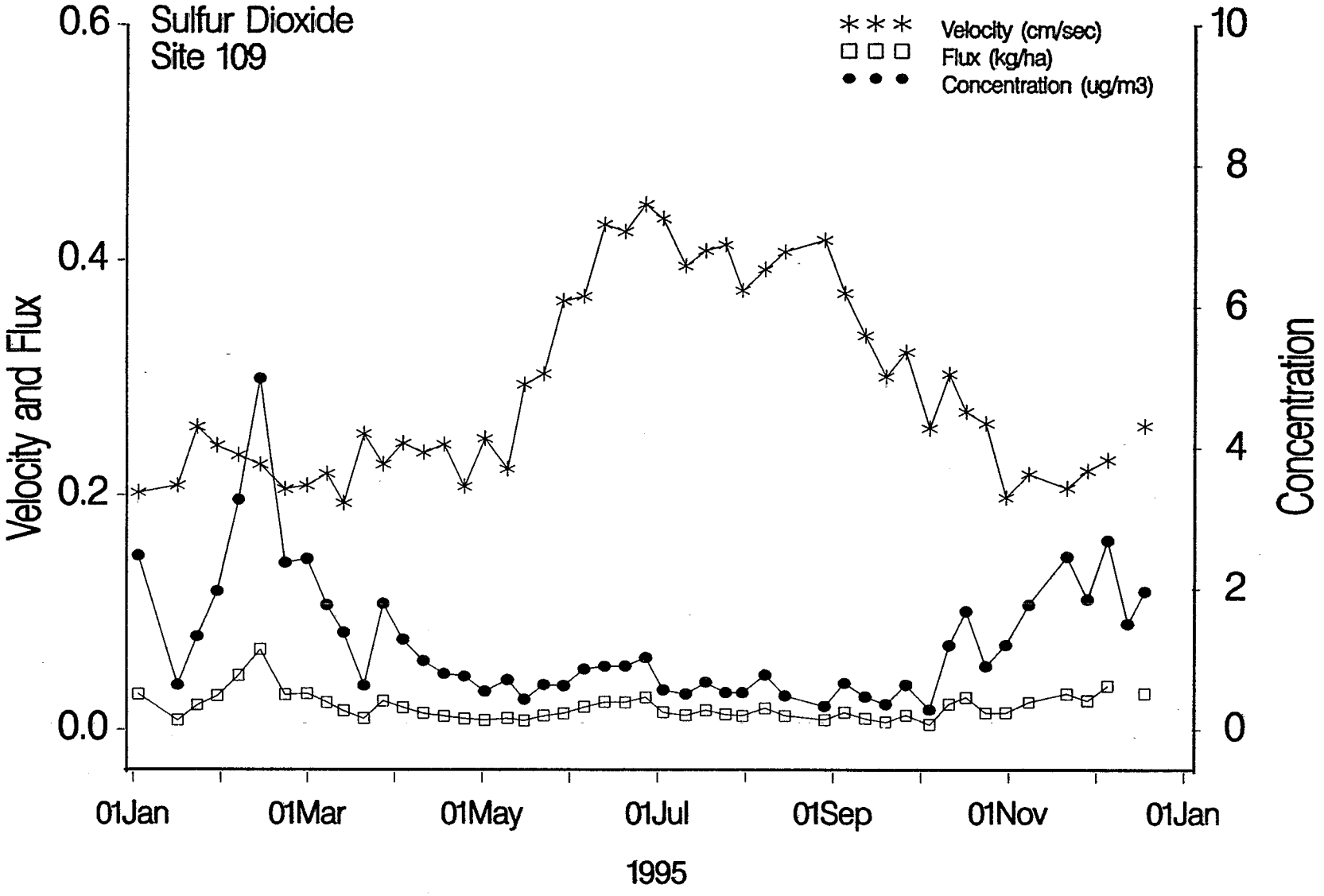


Figure 3-67. Weekly SO_2 concentrations, deposition velocities, and fluxes for Site 109 (1995)

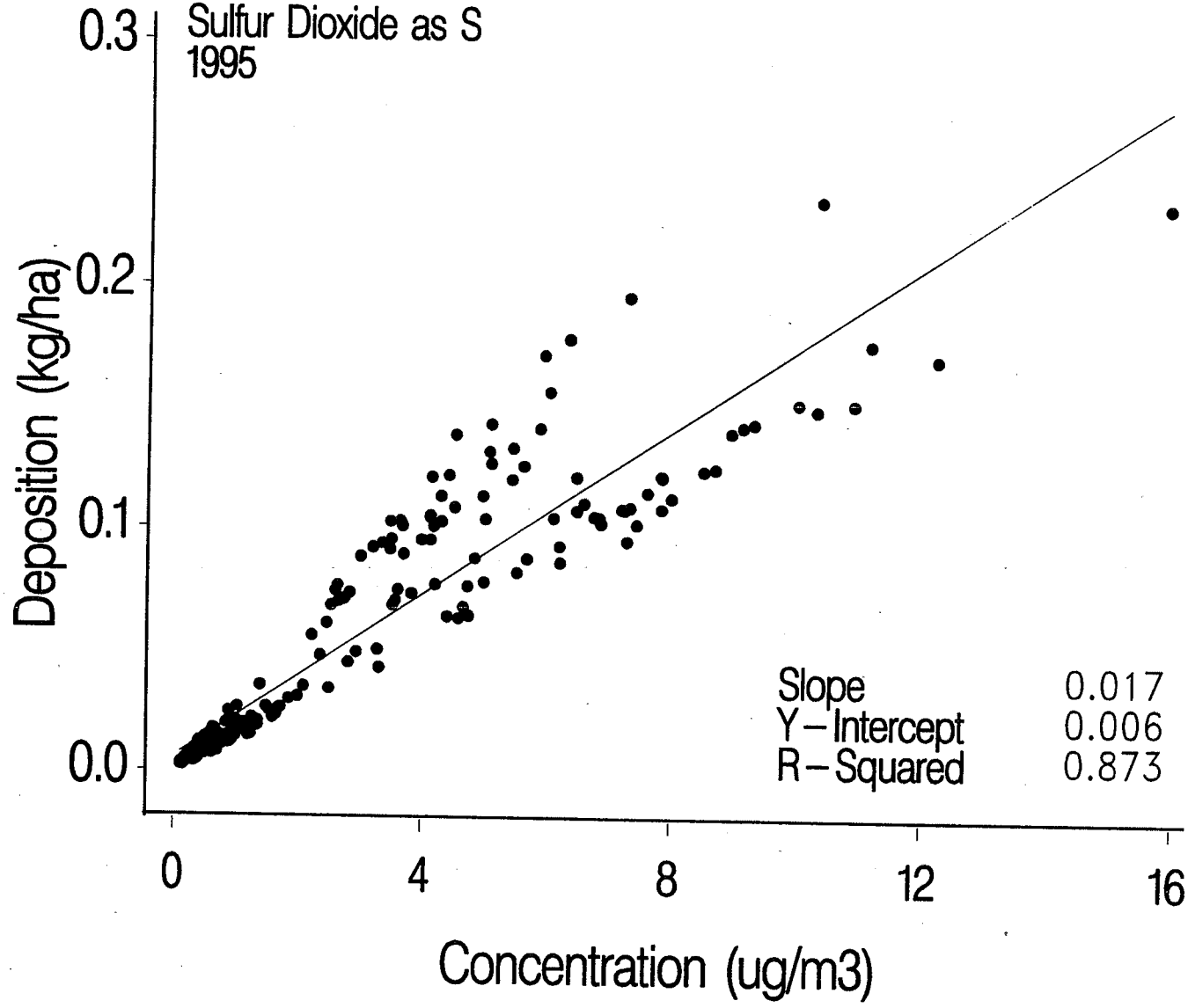


Figure 3-68. Scattergram of weekly SO_2 concentrations and depositions for the five sites combined (1995)

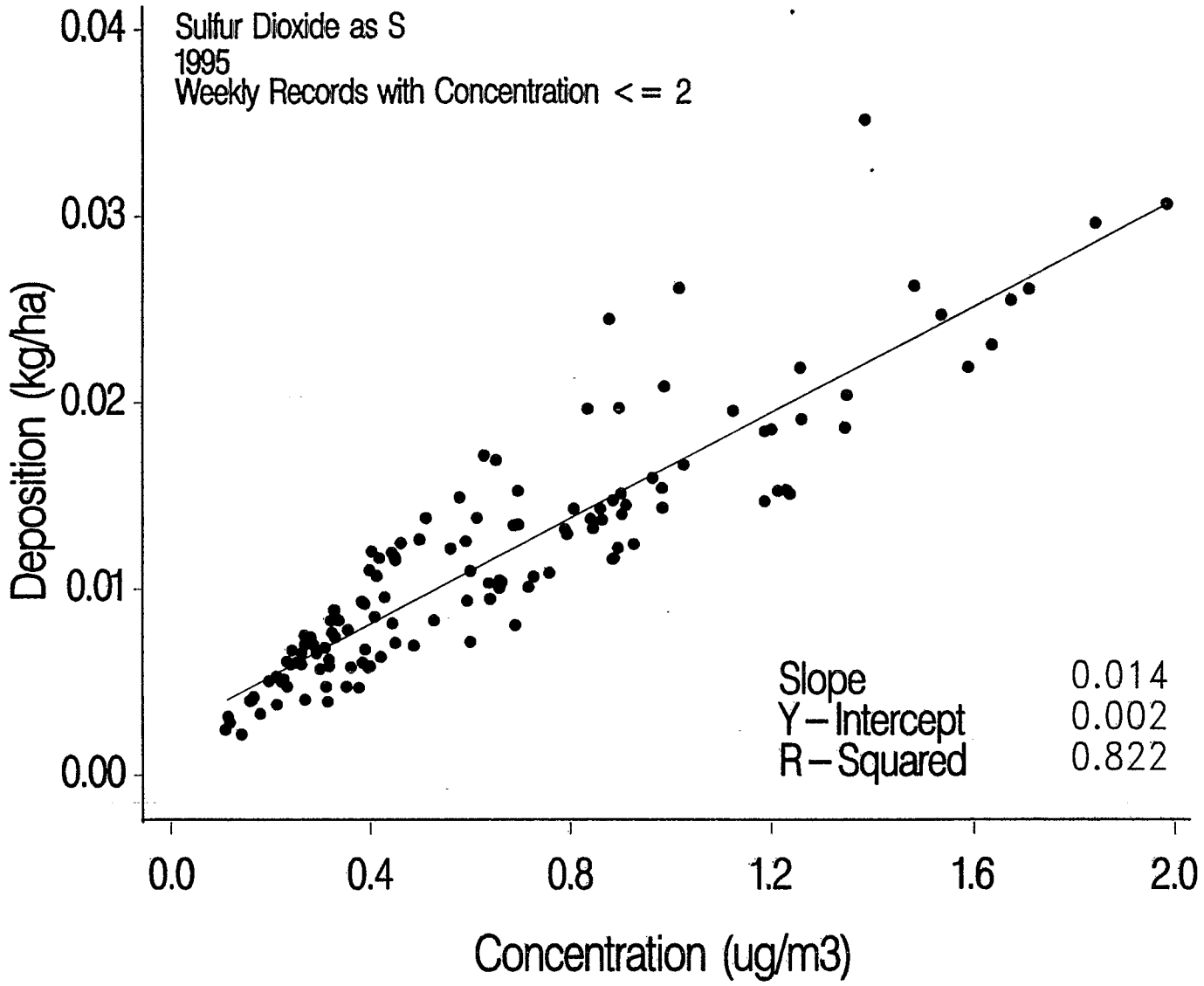


Figure 3-69. Scattergram of SO_2 concentrations less than or equal to 2 $\mu g/m^3$ in 1995 for the five sites combined

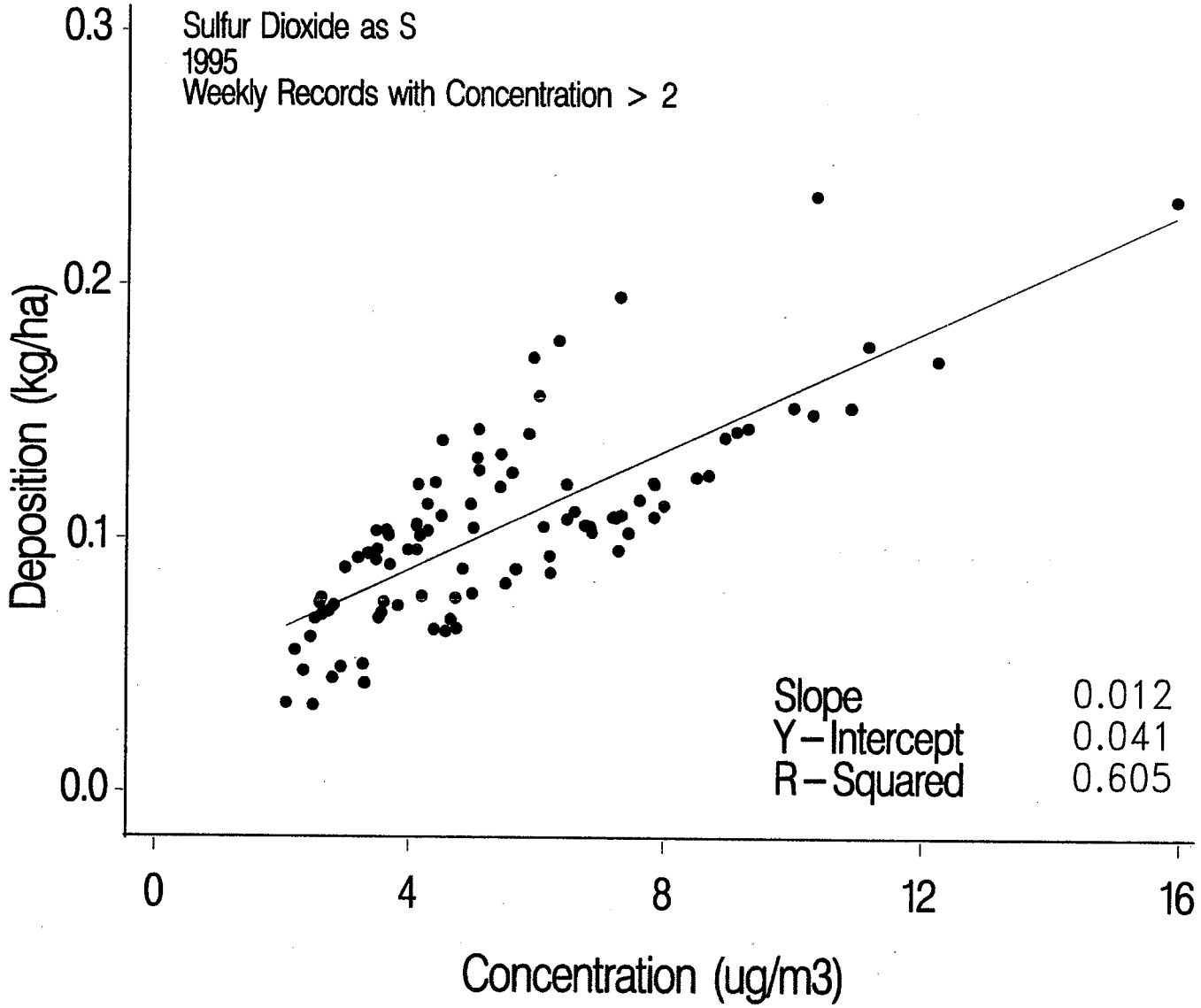


Figure 3-70. Scattergram of SO_2 concentrations greater than 2 $\mu g/m^3$ in 1995 for the five sites combined

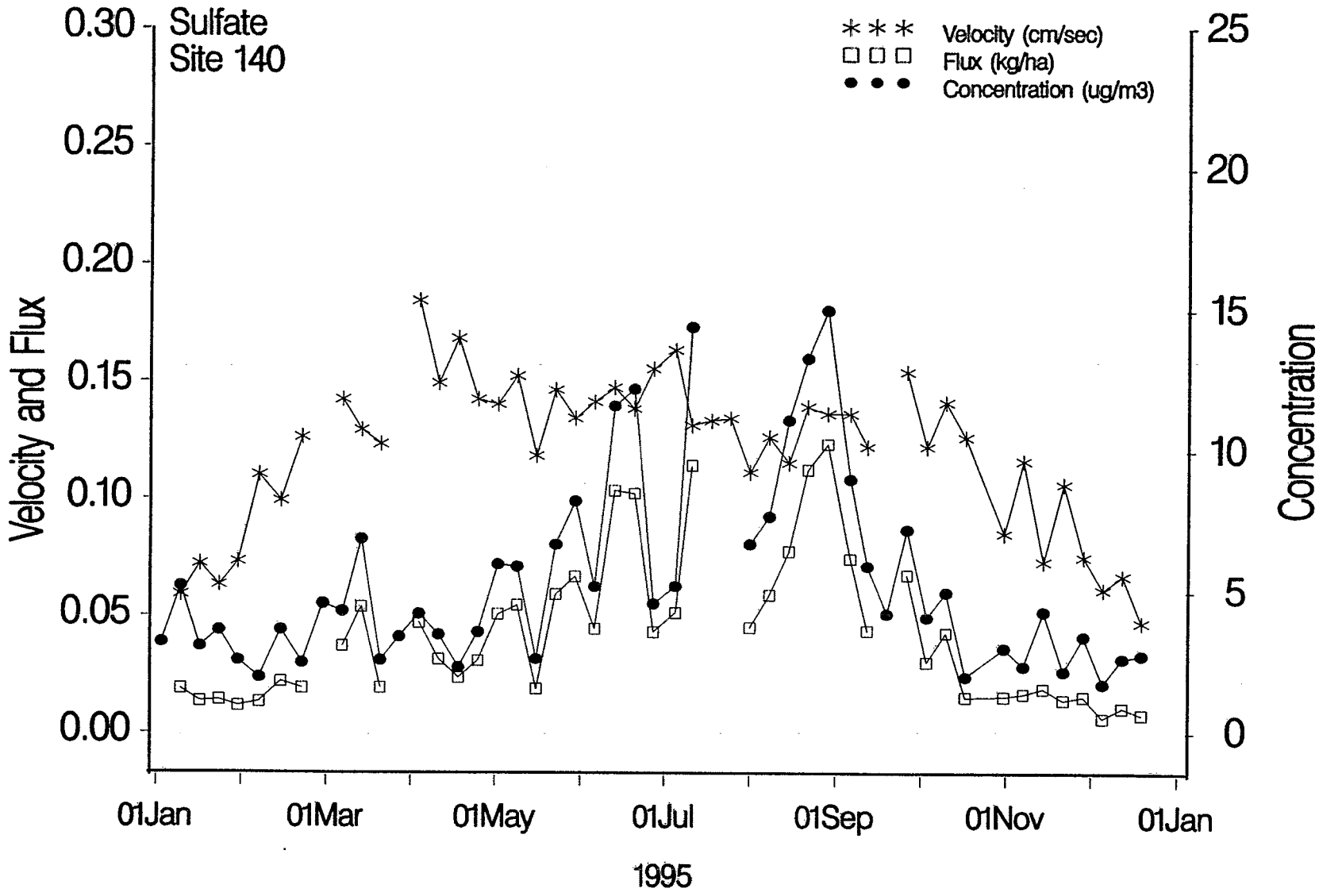


Figure 3-71. Weekly SO_4^{2-} concentrations, deposition velocities, and fluxes for Site 140 (1995)

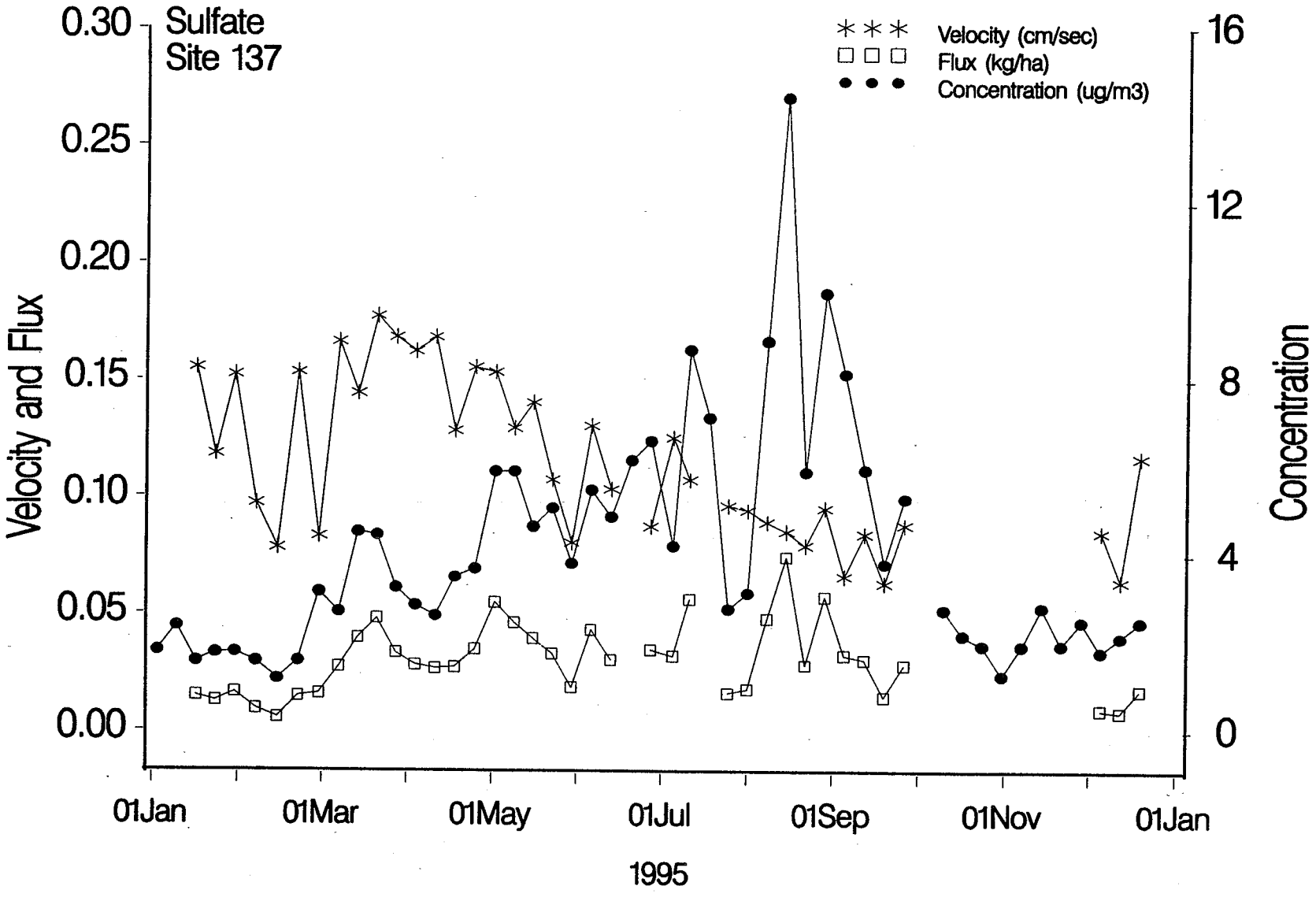


Figure 3-72. Weekly SO_4^{2-} concentrations, deposition velocities, and fluxes for Site 137 (1995)

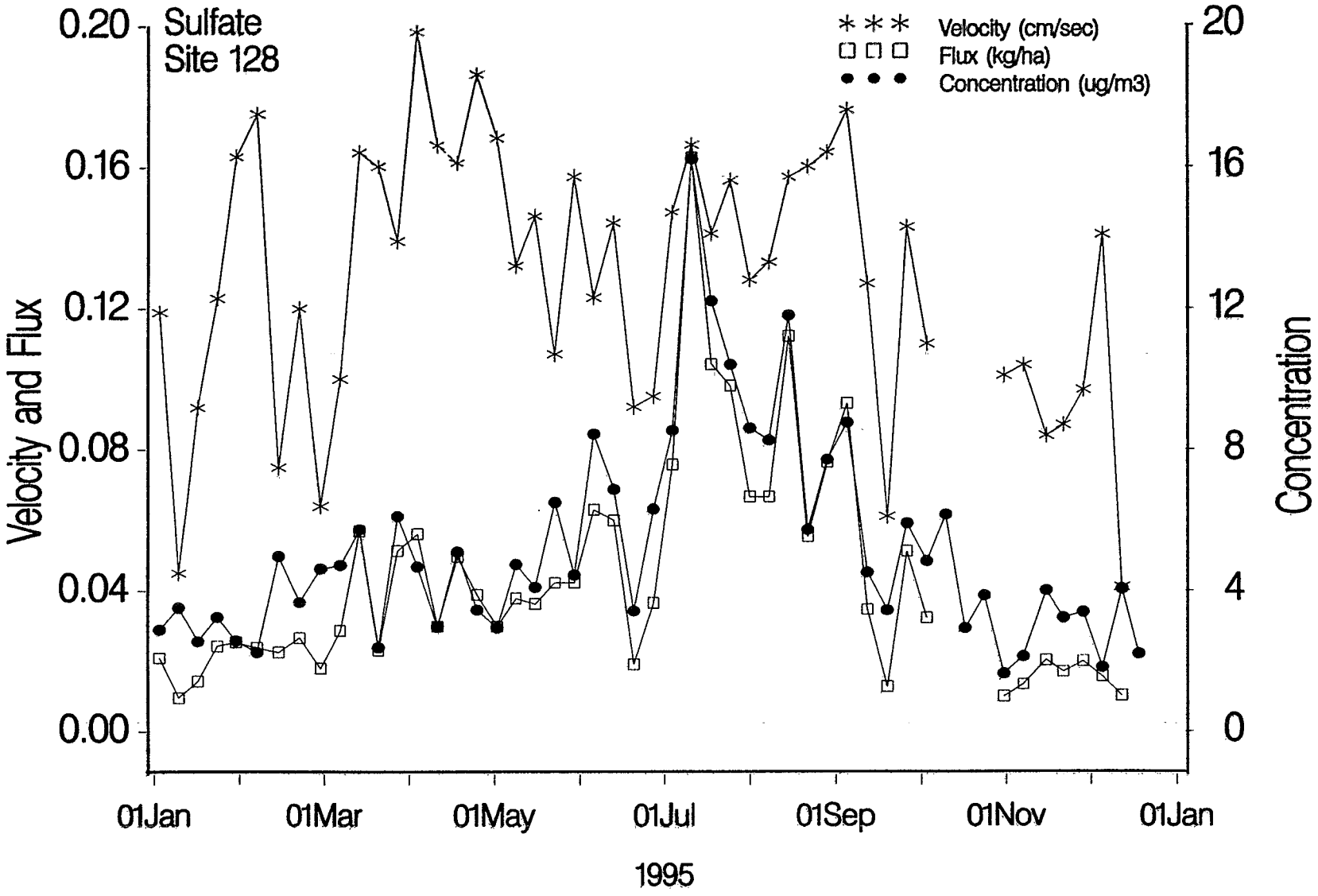


Figure 3-73. Weekly SO_4^{2-} concentrations, deposition velocities, and fluxes for Site 128 (1995)

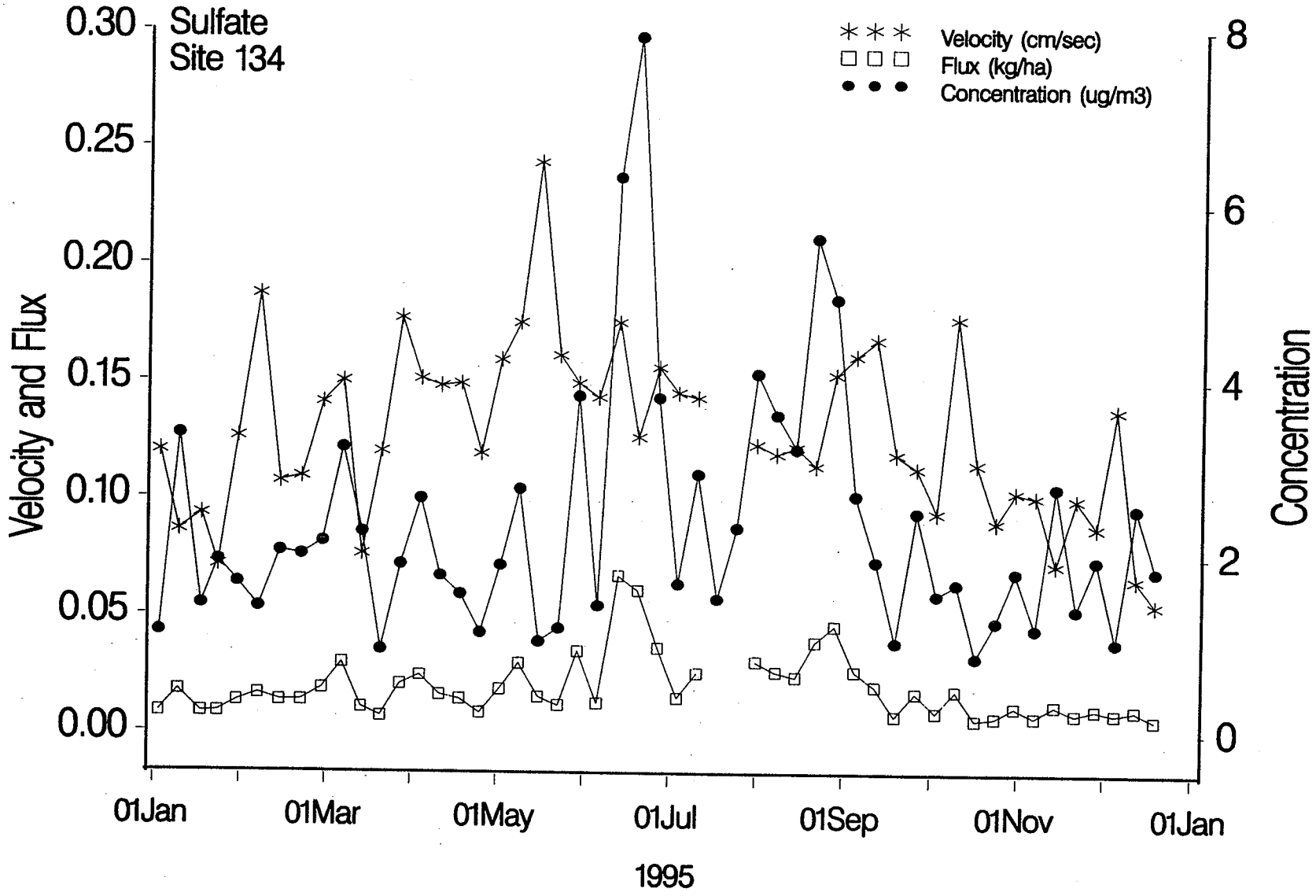


Figure 3-74. Weekly SO_4^{2-} concentrations, deposition velocities, and fluxes for Site 134 (1995)

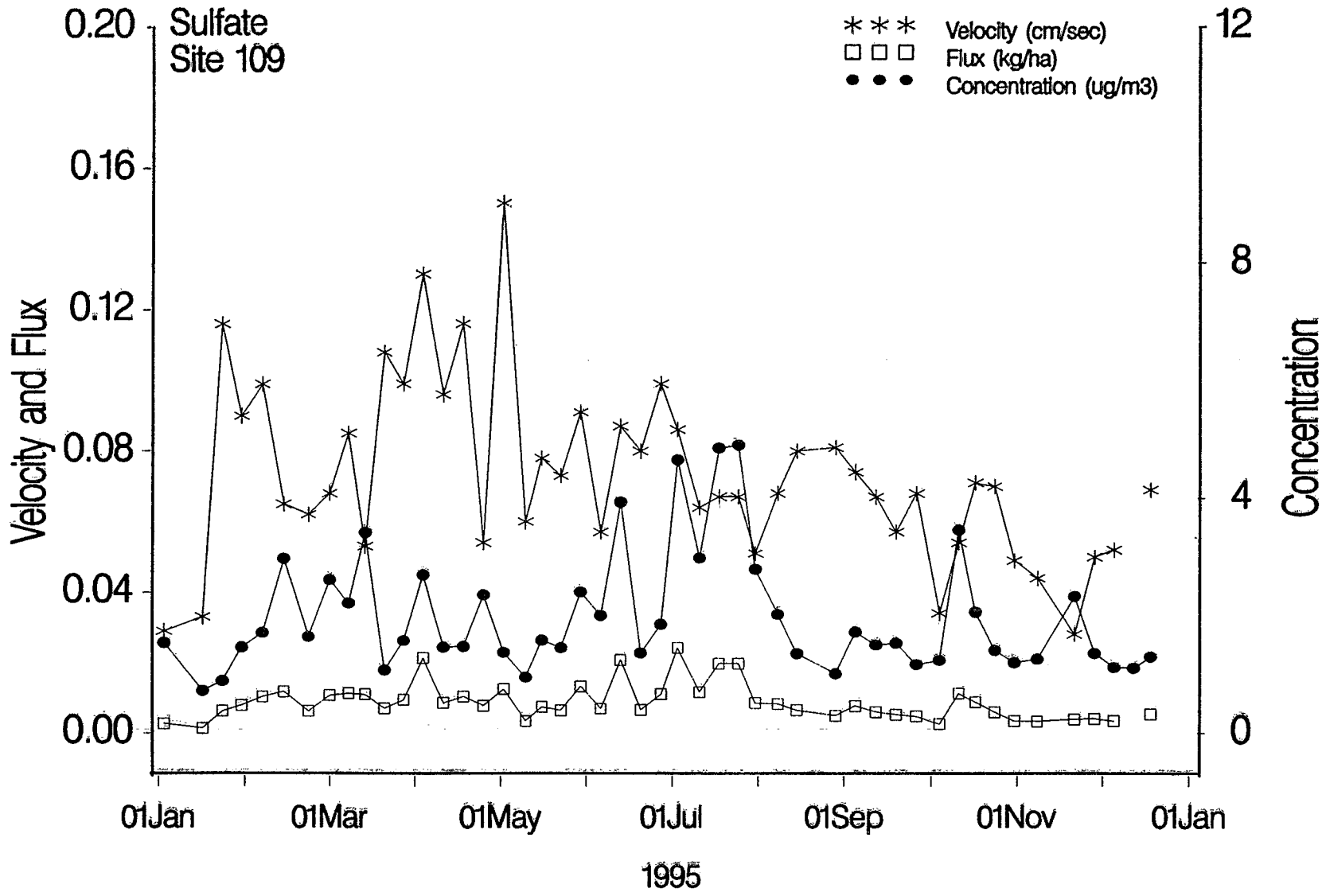


Figure 3-75. Weekly SO_4^{2-} concentrations, deposition velocities, and fluxes for Site 109 (1995)

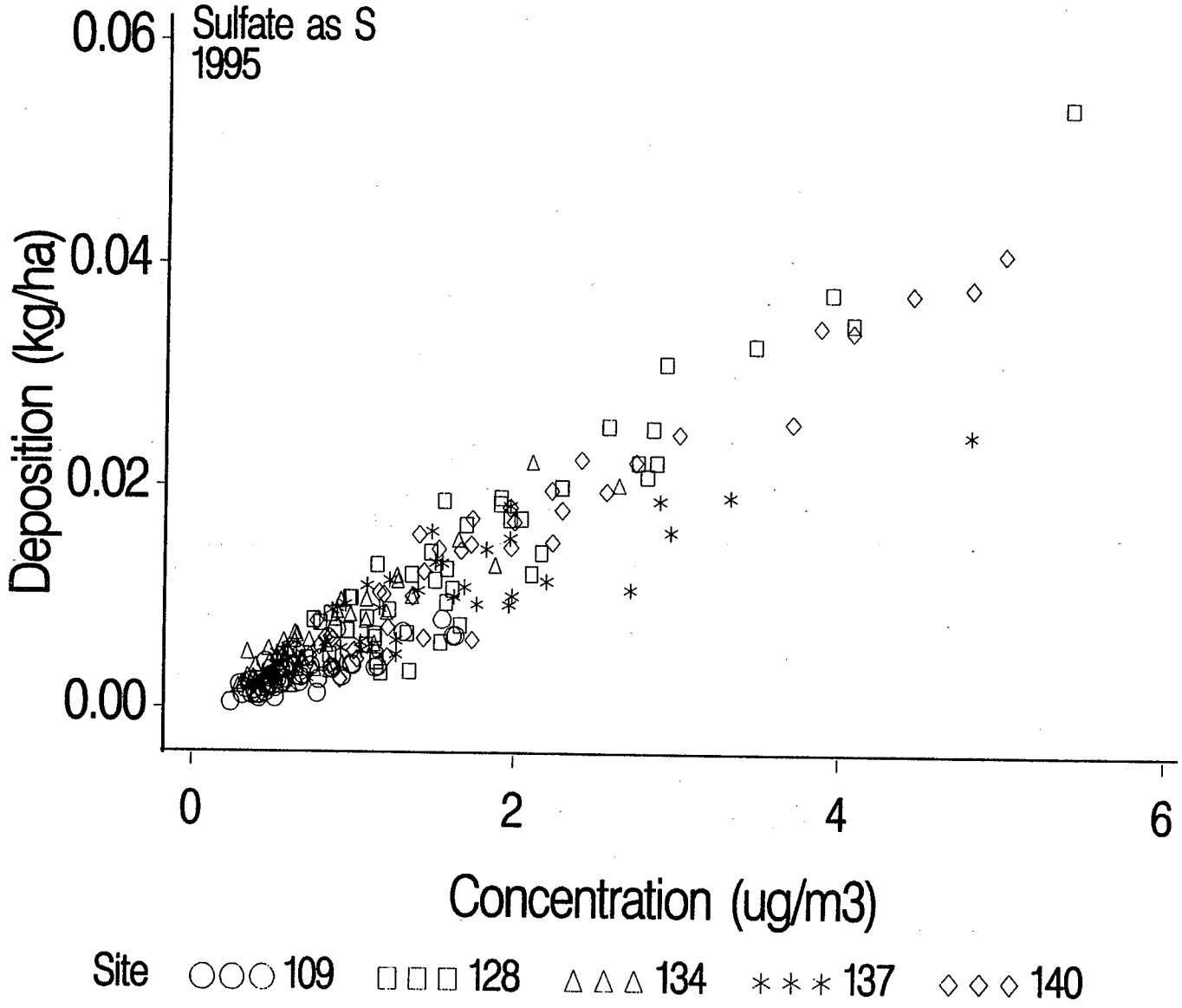


Figure 3-76. Scattergram of weekly SO_4^{2-} concentrations and depositions for the five sites combined (1995)

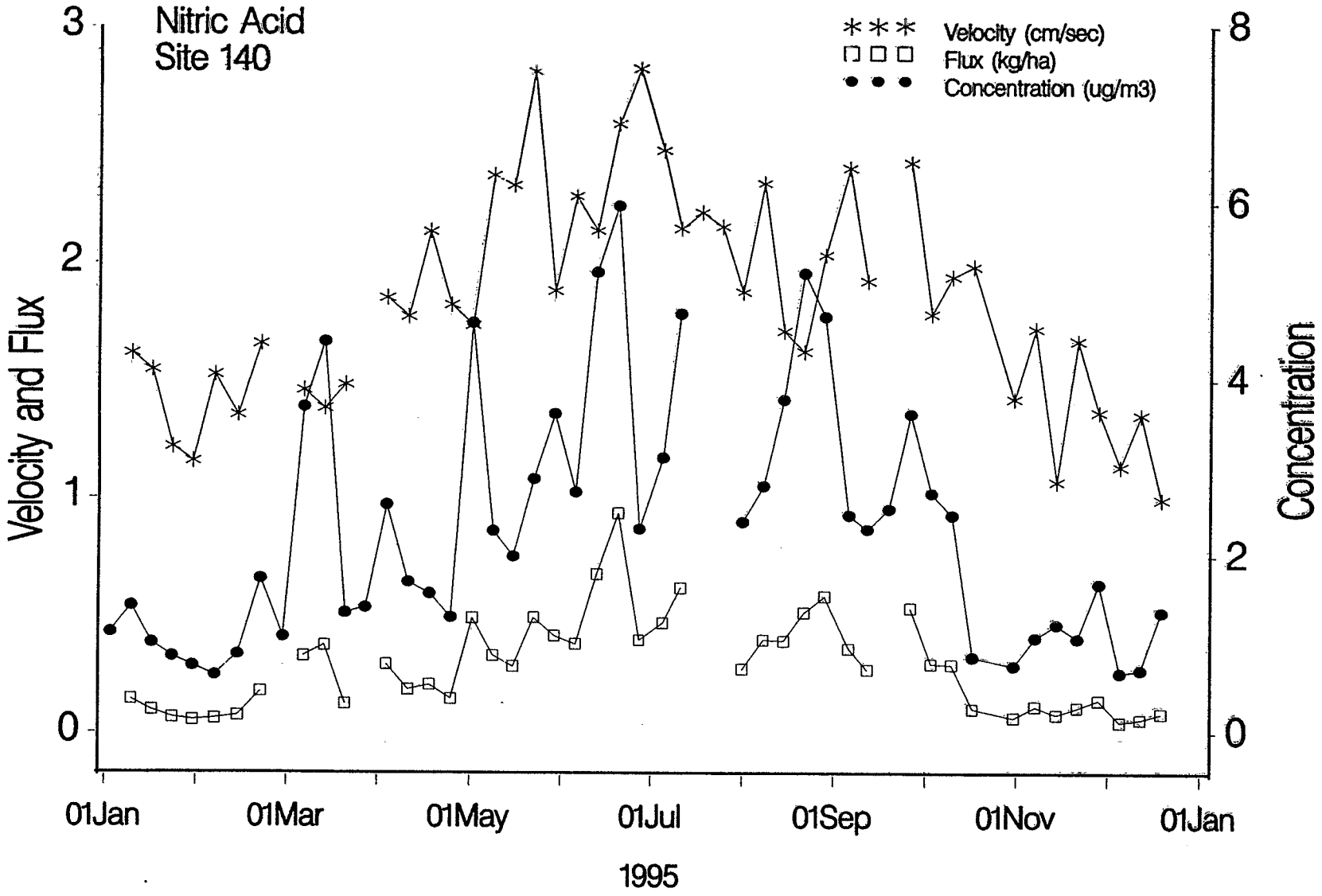


Figure 3-77. Weekly HNO_3 concentrations, deposition velocities, and fluxes for Site 140 (1995)

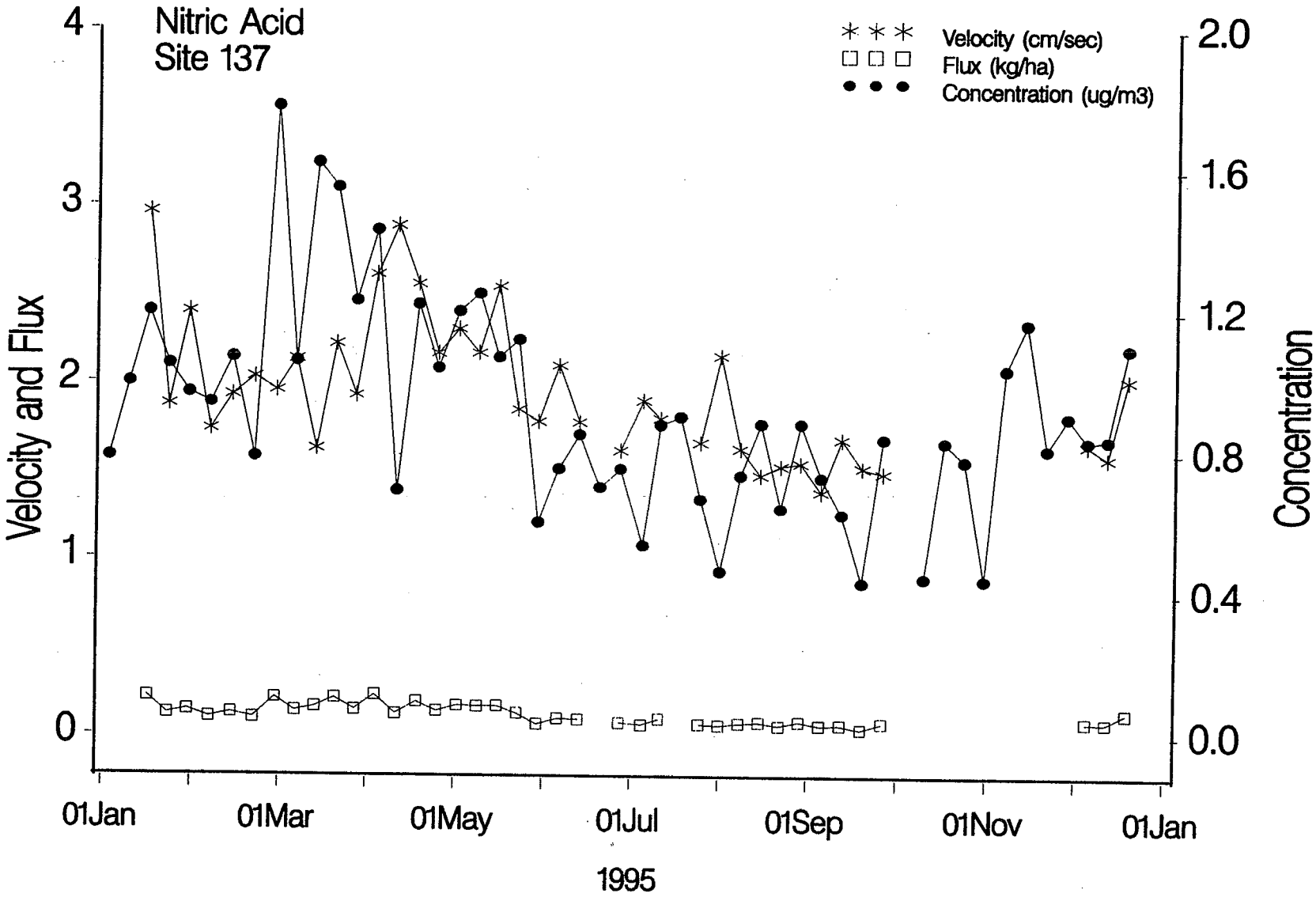


Figure 3-78. Weekly HNO_3 concentrations, deposition velocities, and fluxes for Site 137 (1995)

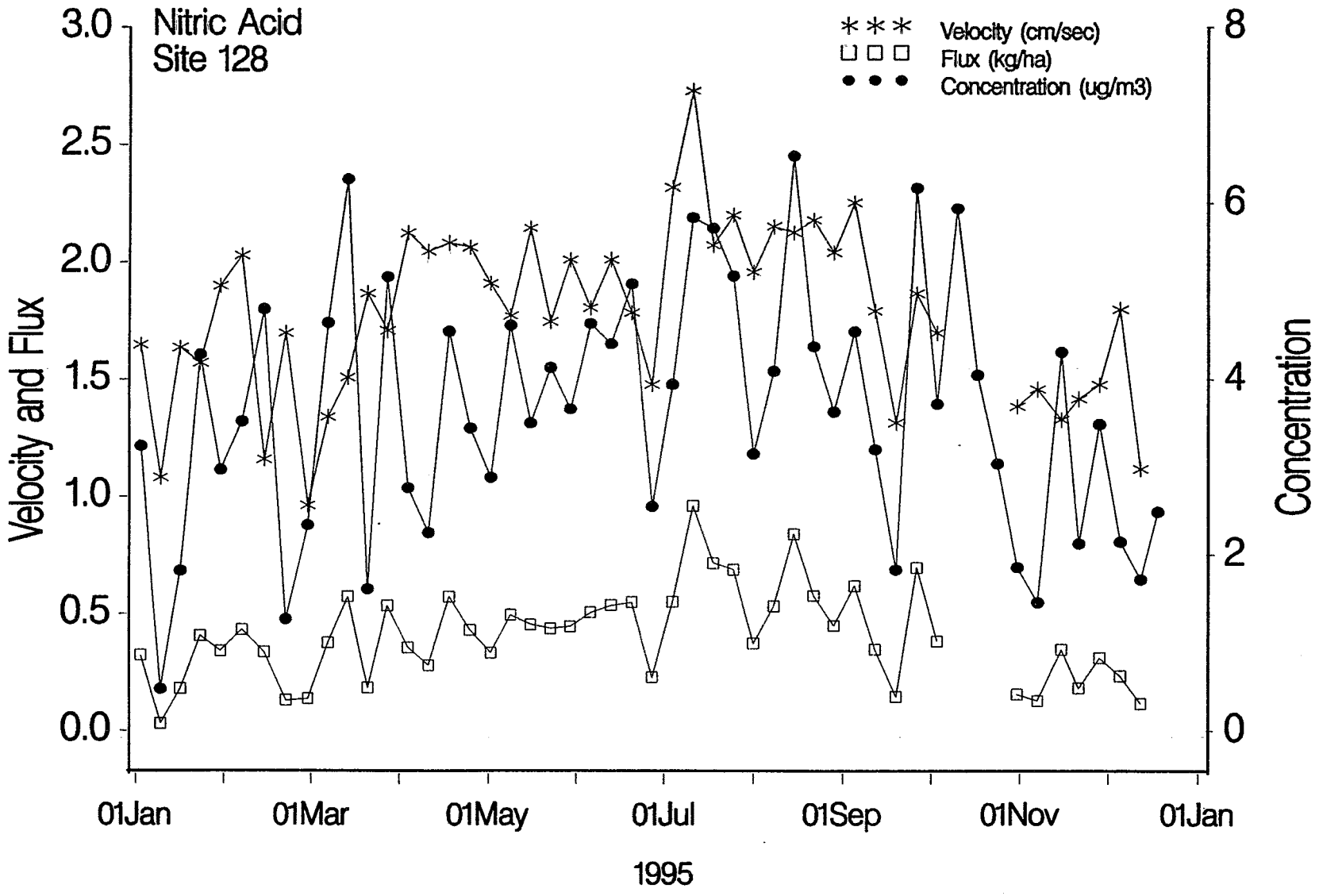


Figure 3-79. Weekly HNO_3 concentrations, deposition velocities, and fluxes for Site 128 (1995)

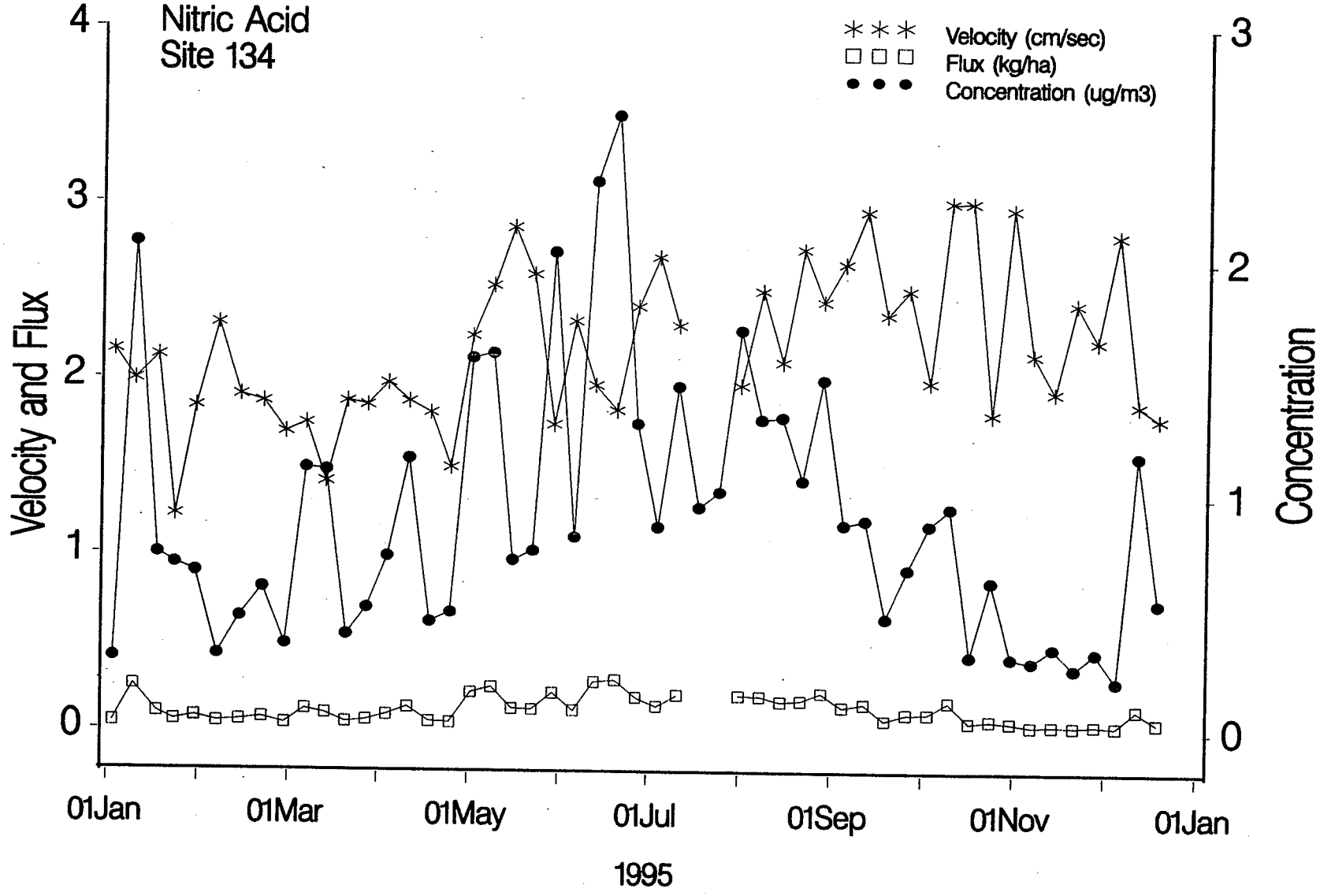


Figure 3-80. Weekly HNO_3 concentrations, deposition velocities, and fluxes for Site 134 (1995)

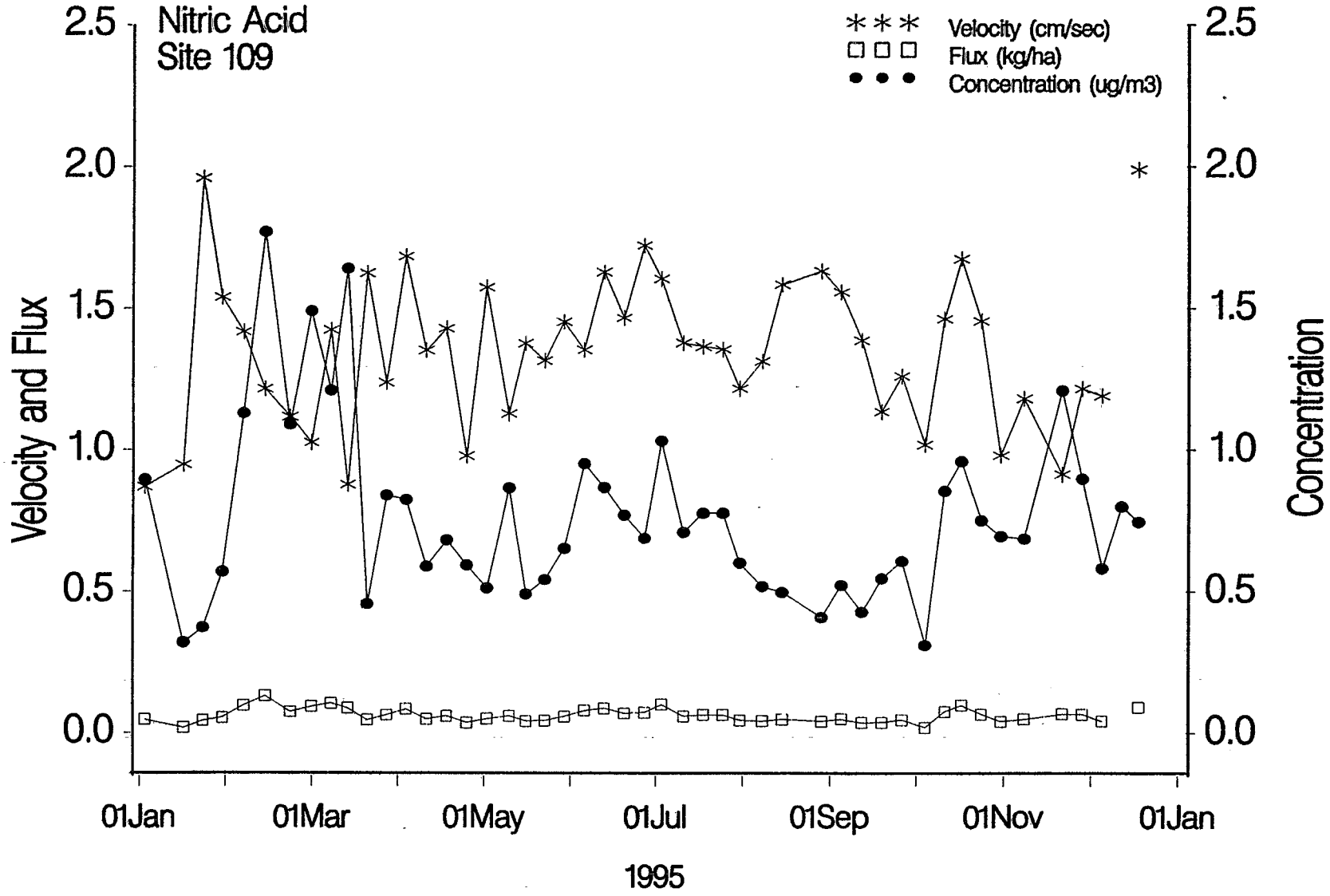


Figure 3-81. Weekly HNO_3 concentrations, deposition velocities, and fluxes for Site 109 (1995)

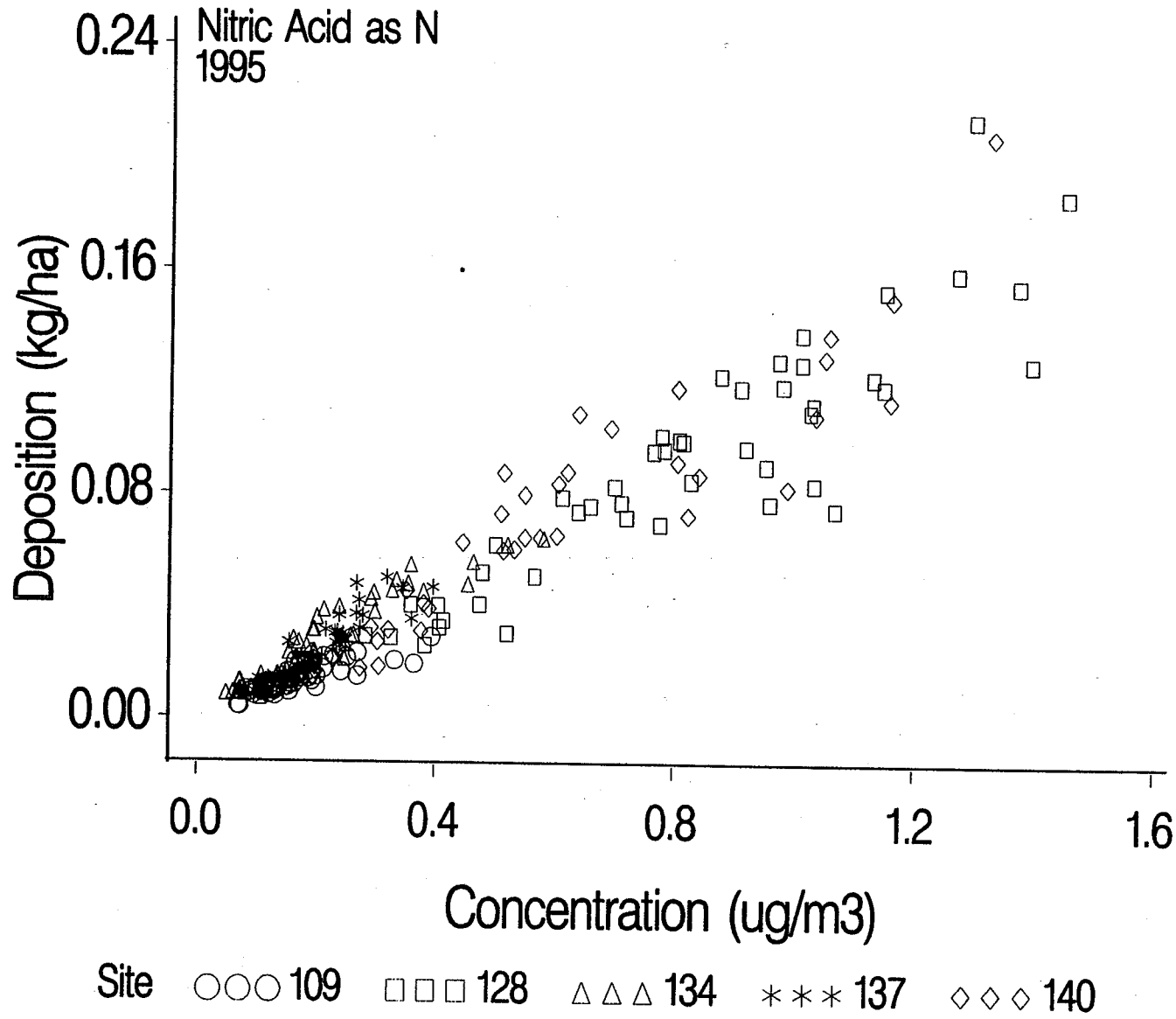


Figure 3-82. Scattergram of weekly HNO_3 concentrations and depositions for the five sites combined (1995)

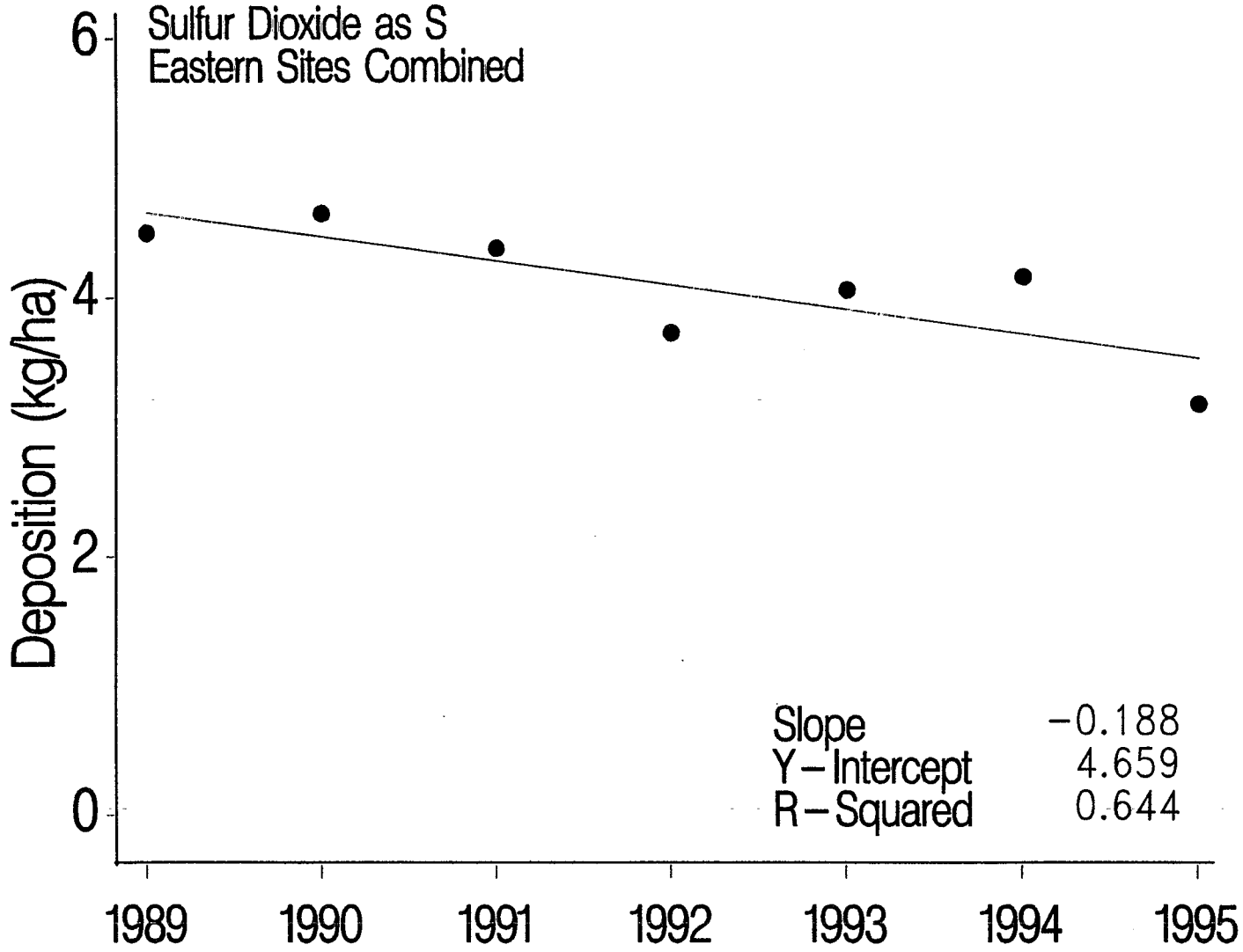


Figure 3-83. Linear regressions of dry SO_2 depositions from 1989 through 1995 for all eastern sites combined

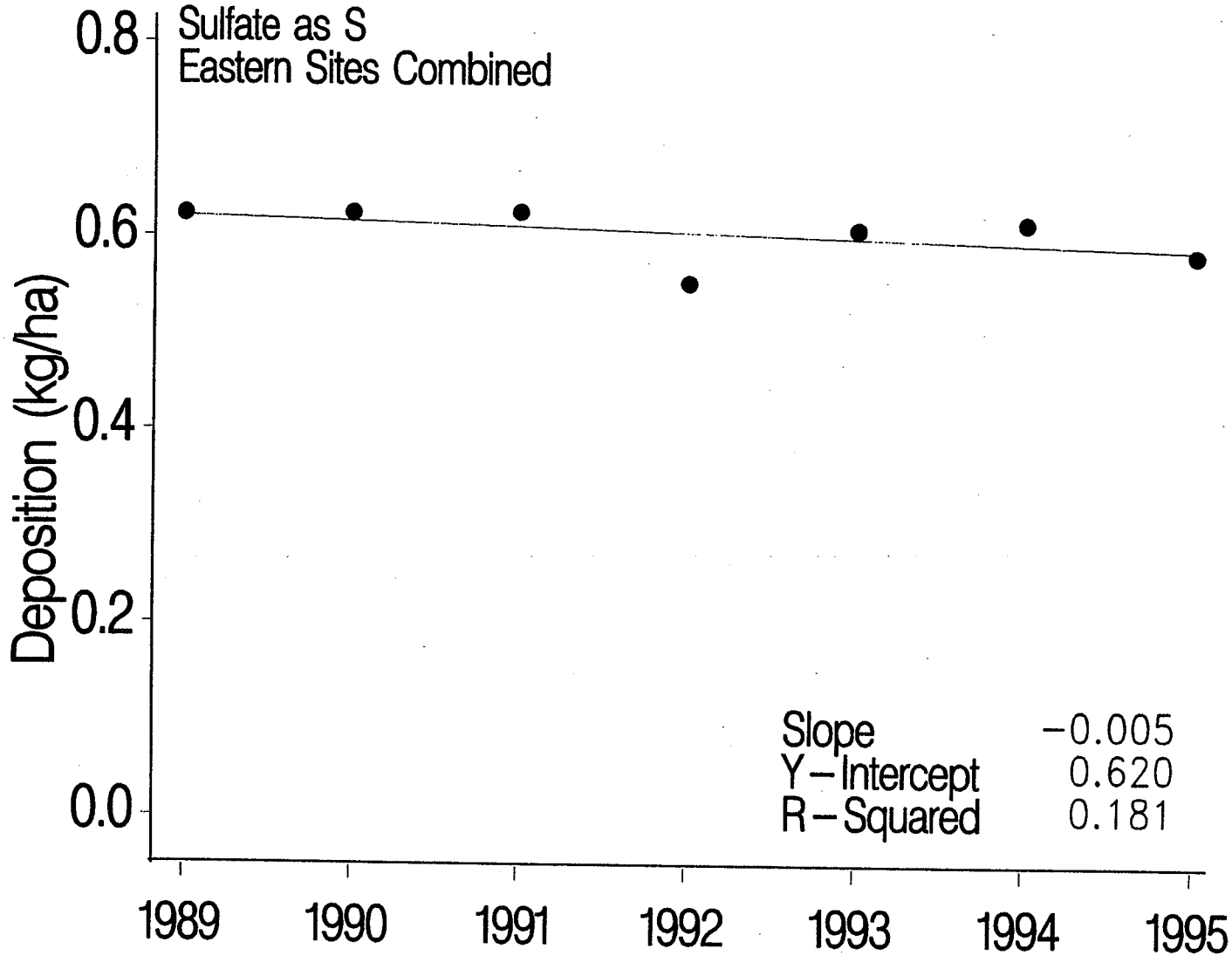


Figure 3-84. Linear regressions of dry SO_4^{2-} depositions from 1989 through 1995 for all eastern sites combined

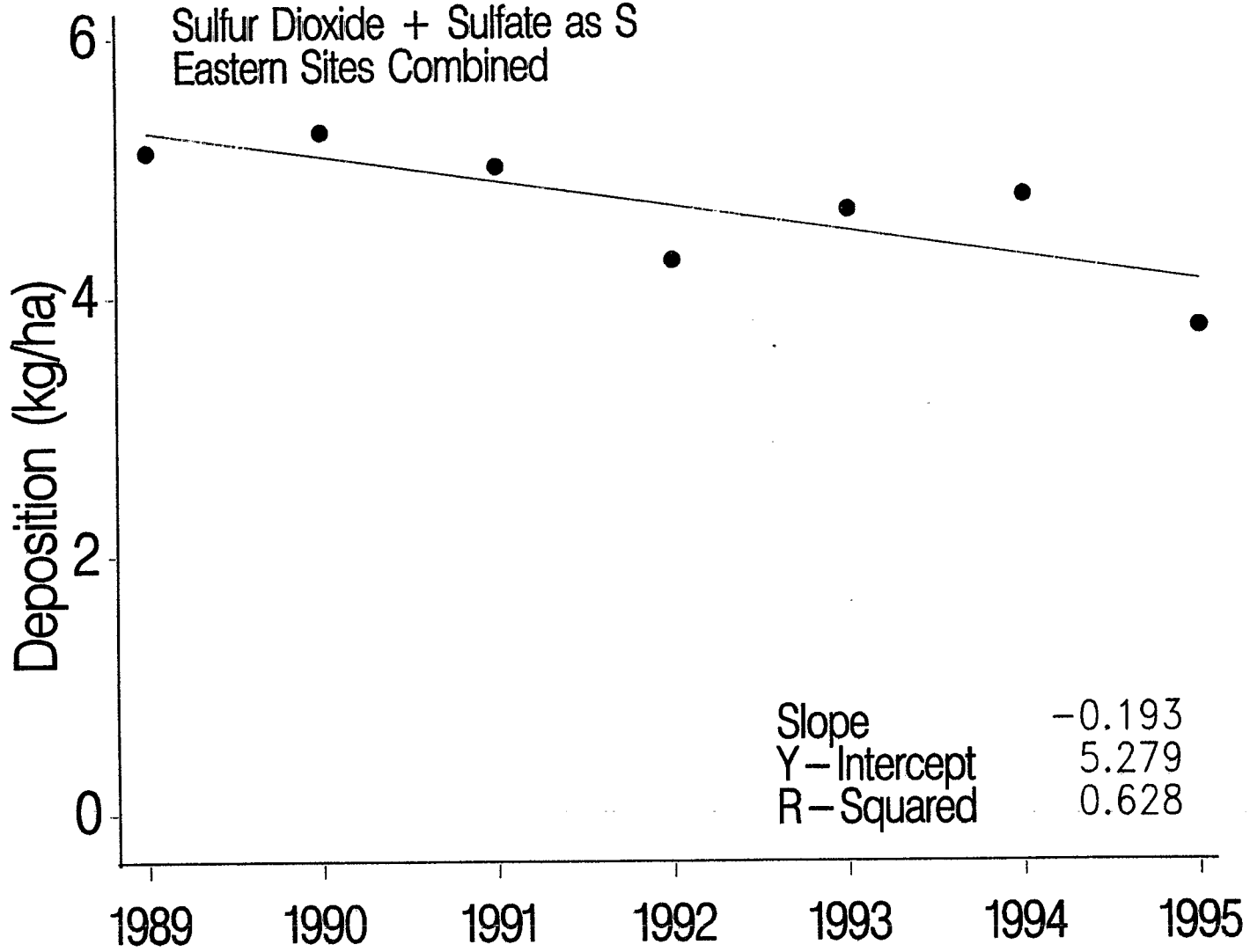


Figure 3-85. Linear regressions of dry sulfur depositions from 1989 through 1995 for all eastern sites combined

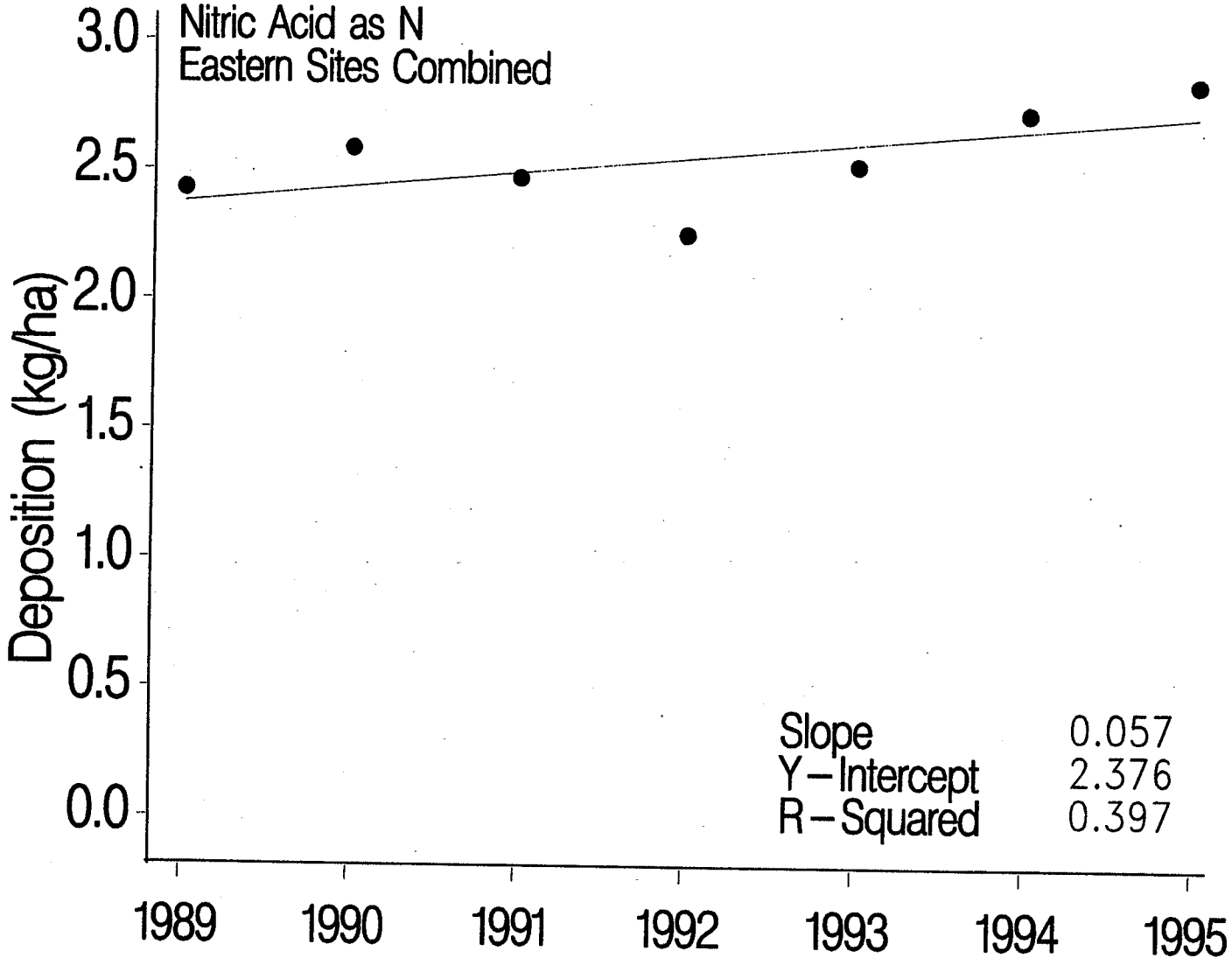


Figure 3-86. Linear regressions of dry HNO_3 depositions from 1989 through 1995 for all eastern sites combined

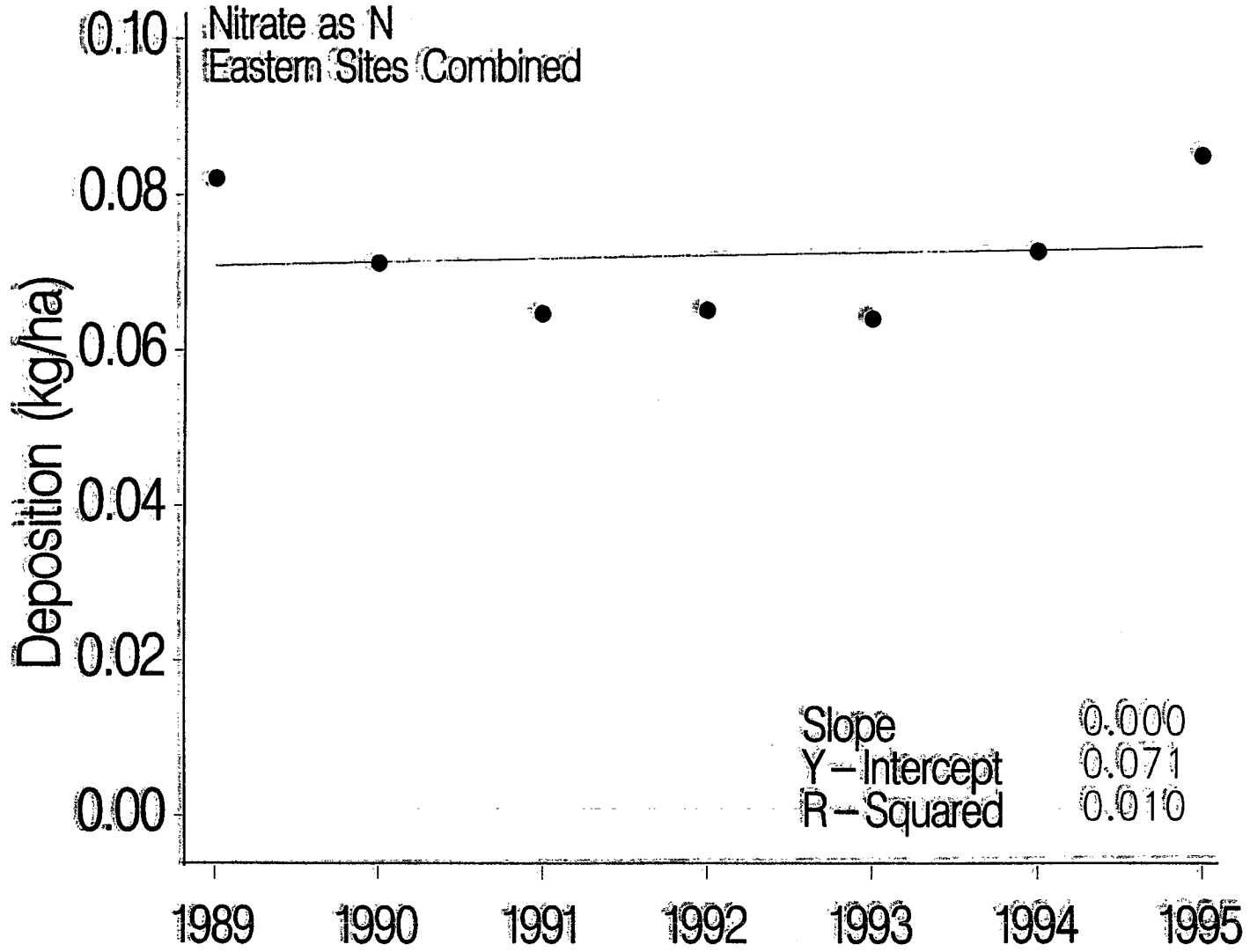


Figure 3-87. Linear regressions of dry NO_3 depositions from 1989 through 1995 for all eastern sites combined

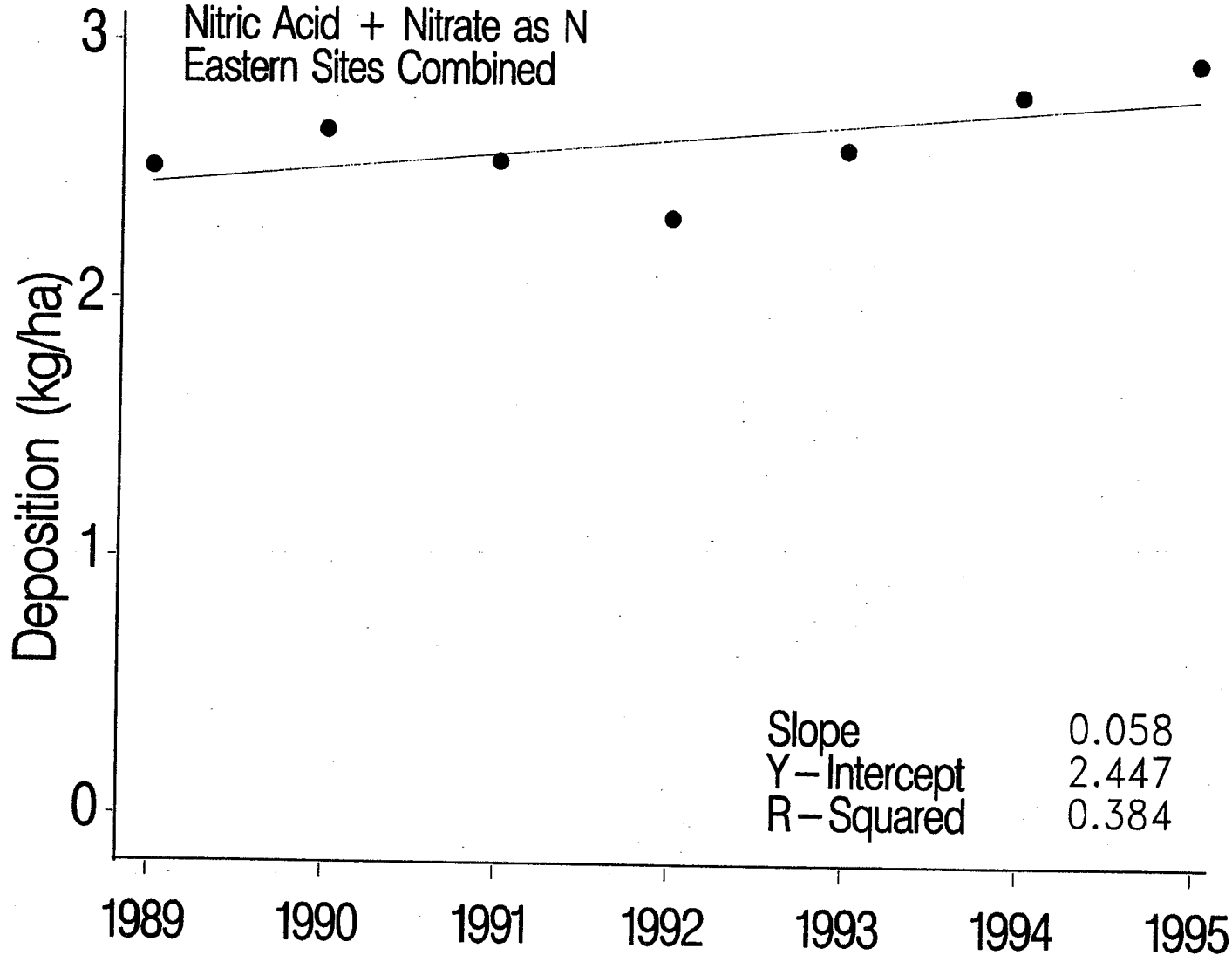


Figure 3-88. Linear regressions of dry nitrogen depositions from 1989 through 1995 for all eastern sites combined

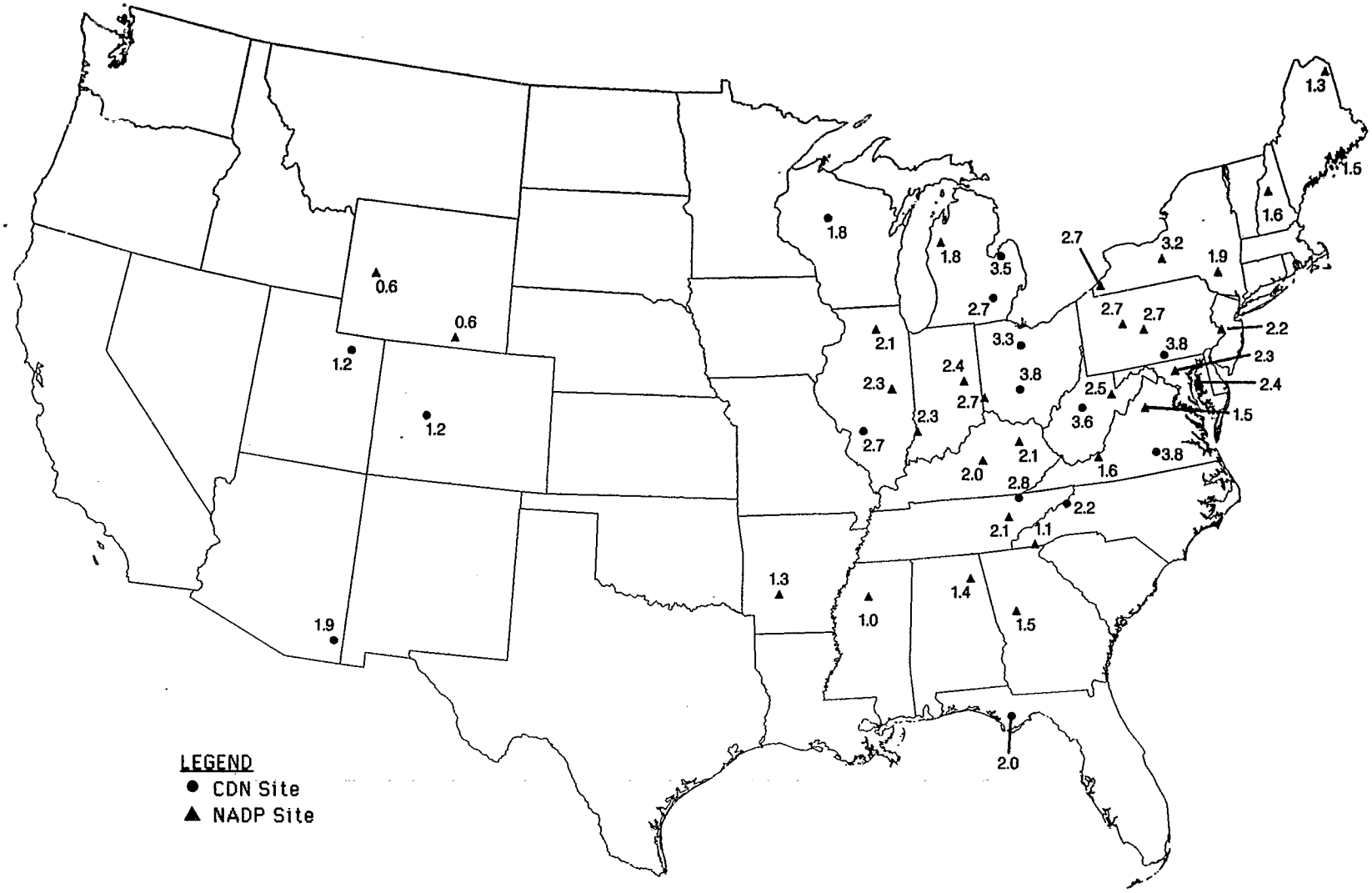


Figure 3-89. Annual average SO_4^{2-} concentrations (mg/L) for 1990 for the combined CDN/NADP database

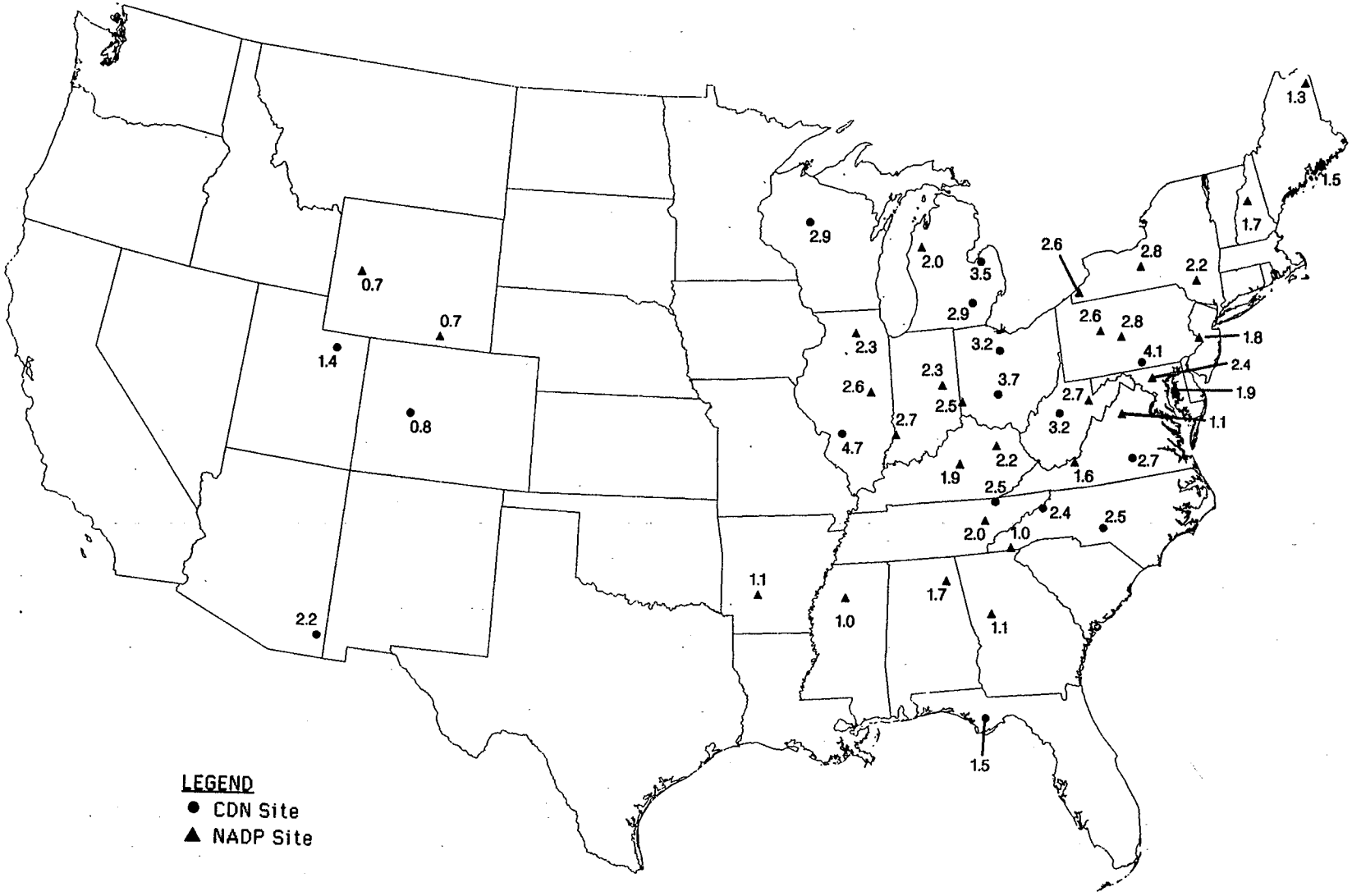


Figure 3-90. Annual average SO_4^{2-} concentrations (mg/L) for 1992 for the combined CDN/NADP database

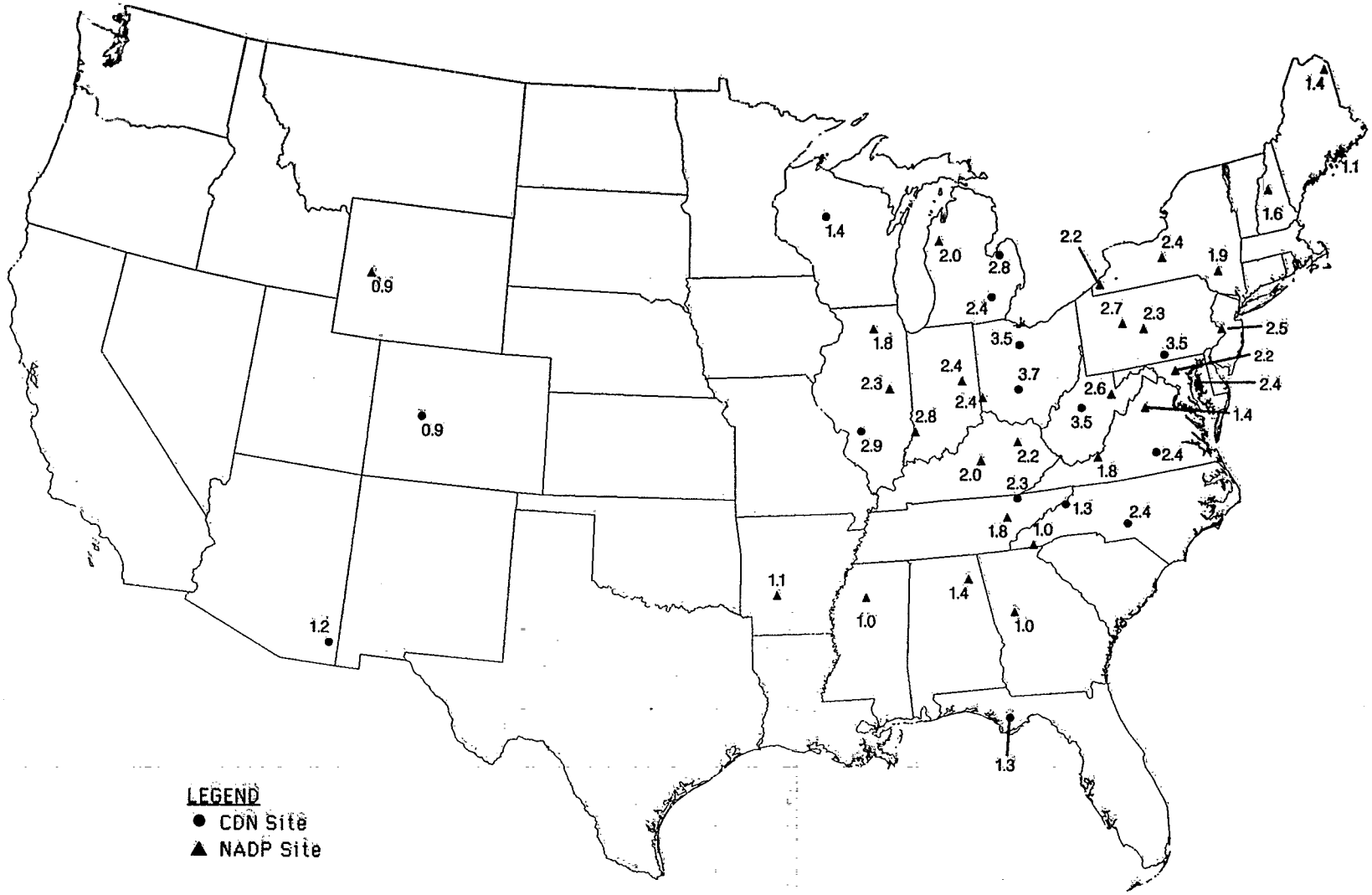


Figure 3-91. Annual average SO_4^{2-} concentrations (mg/L) for 1994 for the combined CDN/NADP database

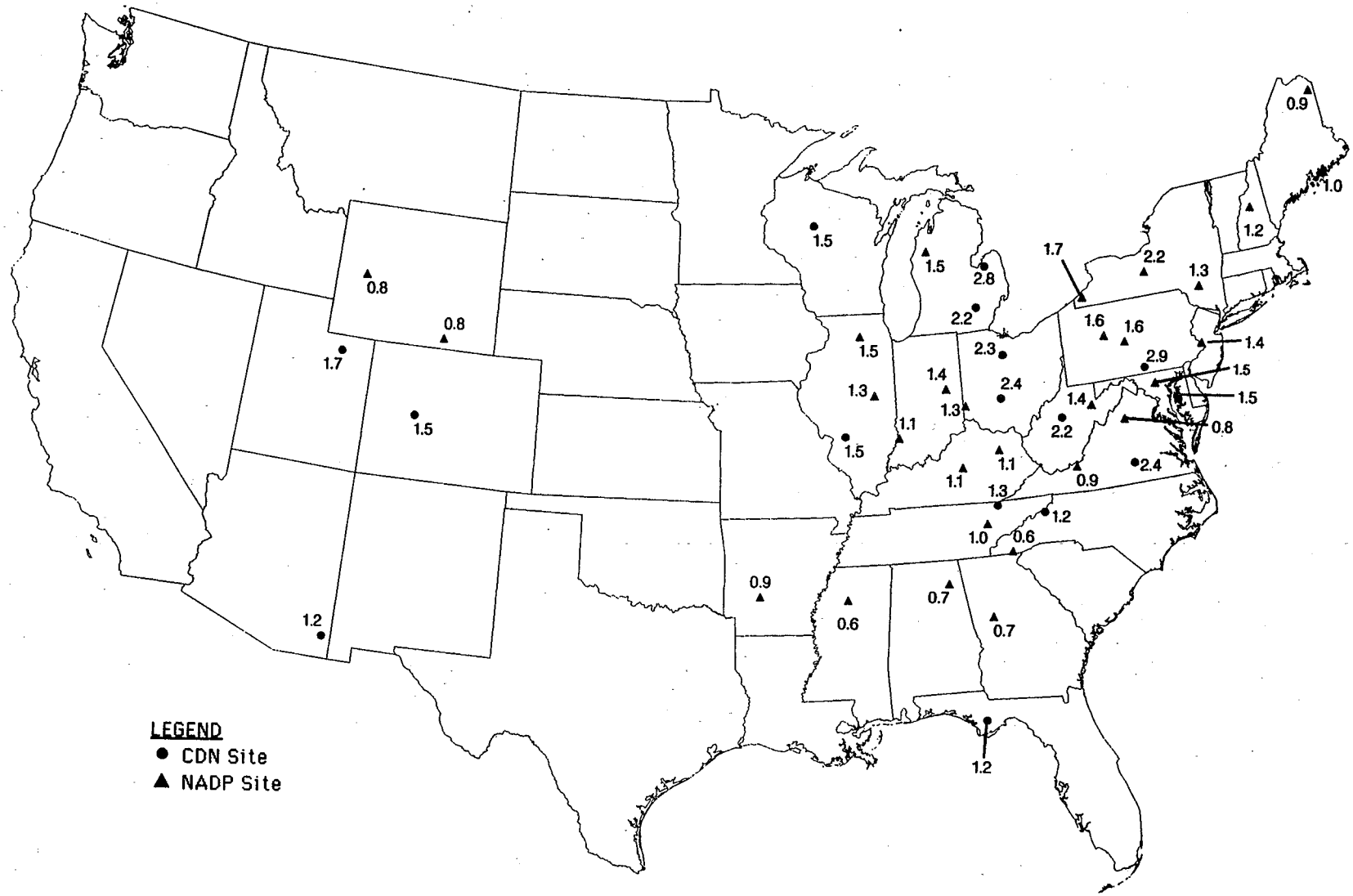


Figure 3-92. Annual average NO_3^- concentrations (mg/L) for 1990 for the combined CDN/NADP database

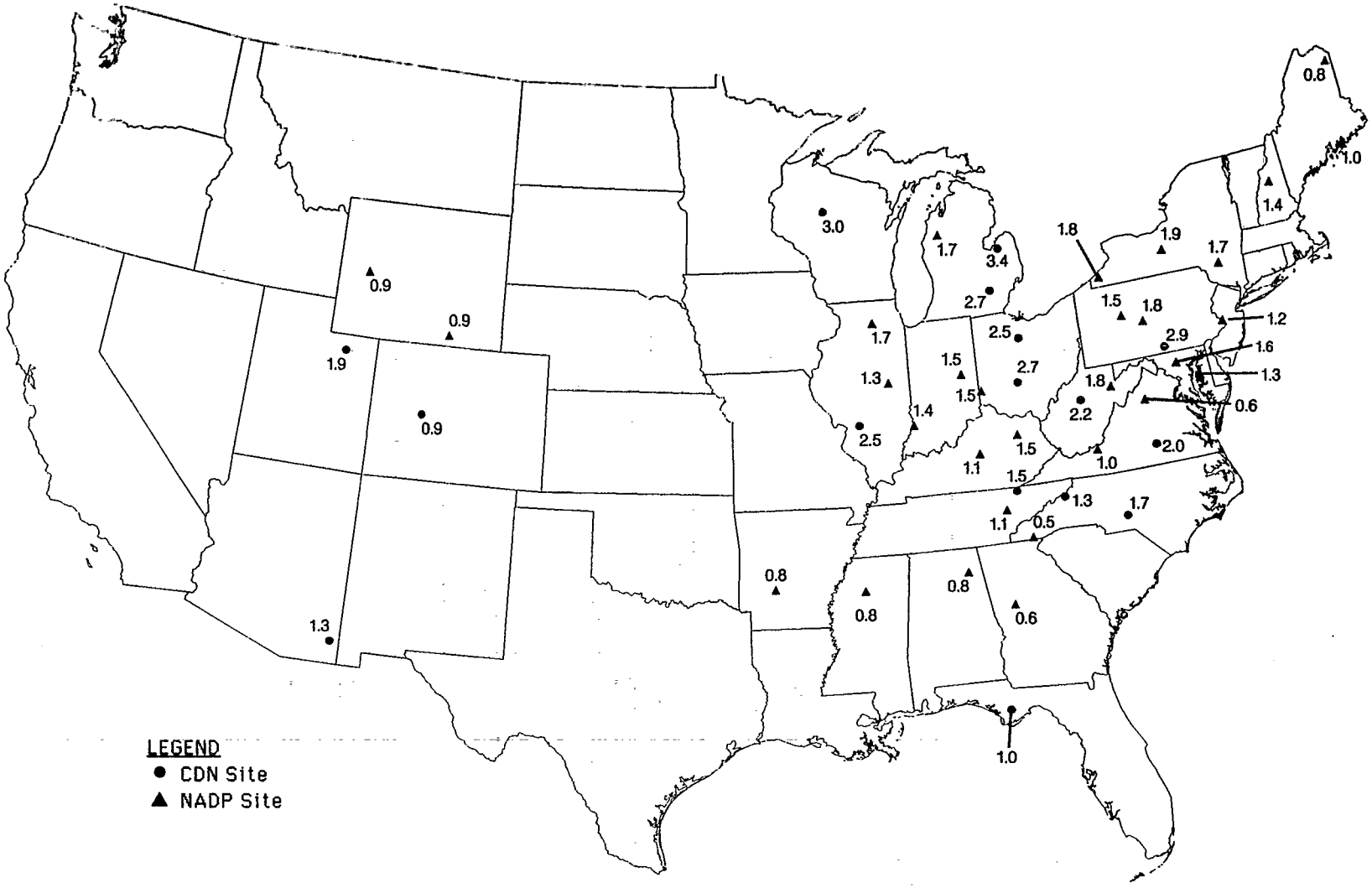


Figure 3-93. Annual average NO_3^- concentrations (mg/L) for 1992 for the combined CDN/NADP database

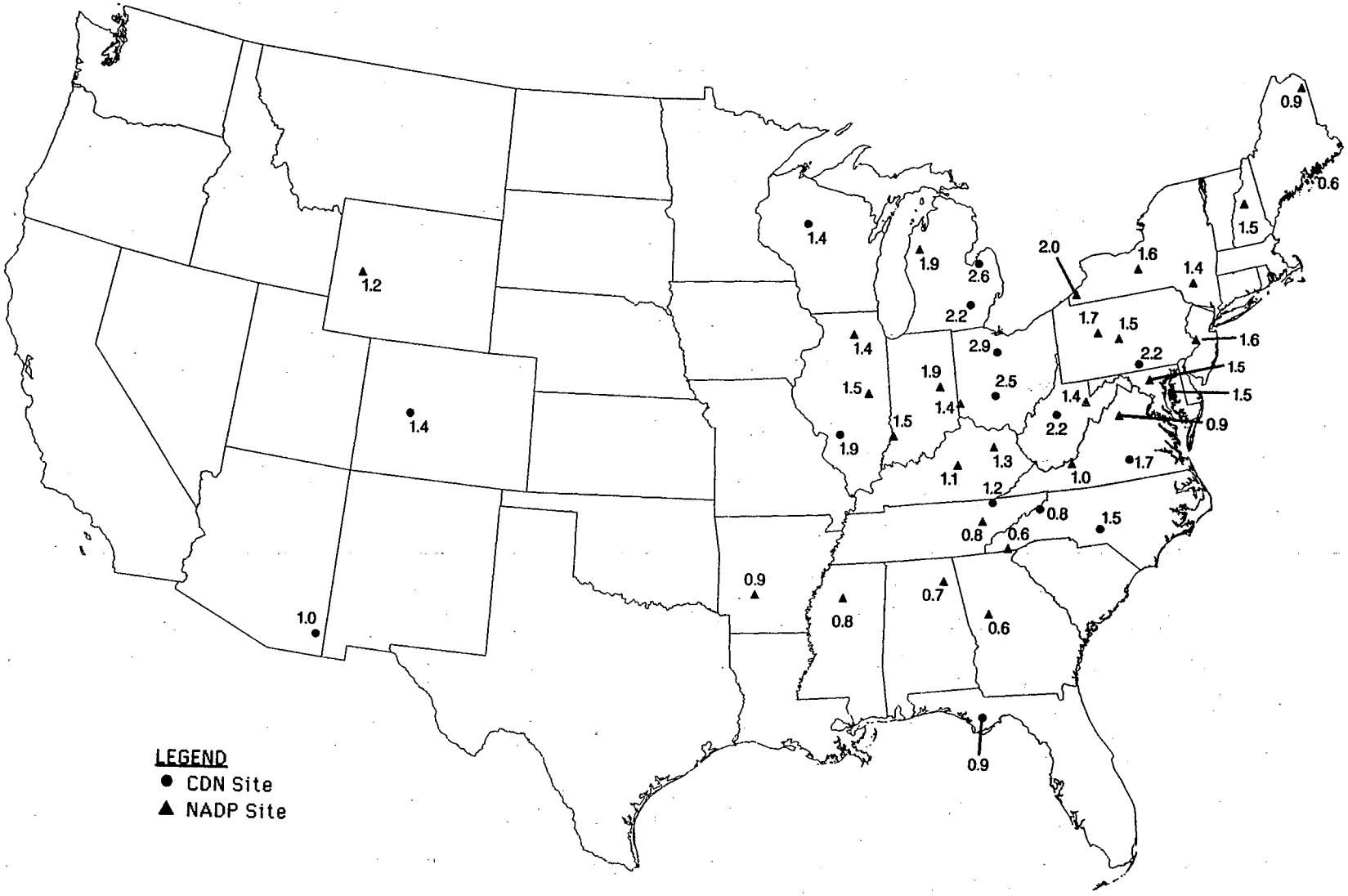


Figure 3-94. Annual average NO_3^- concentrations (mg/L) for 1994 for the combined CDN/NADP database

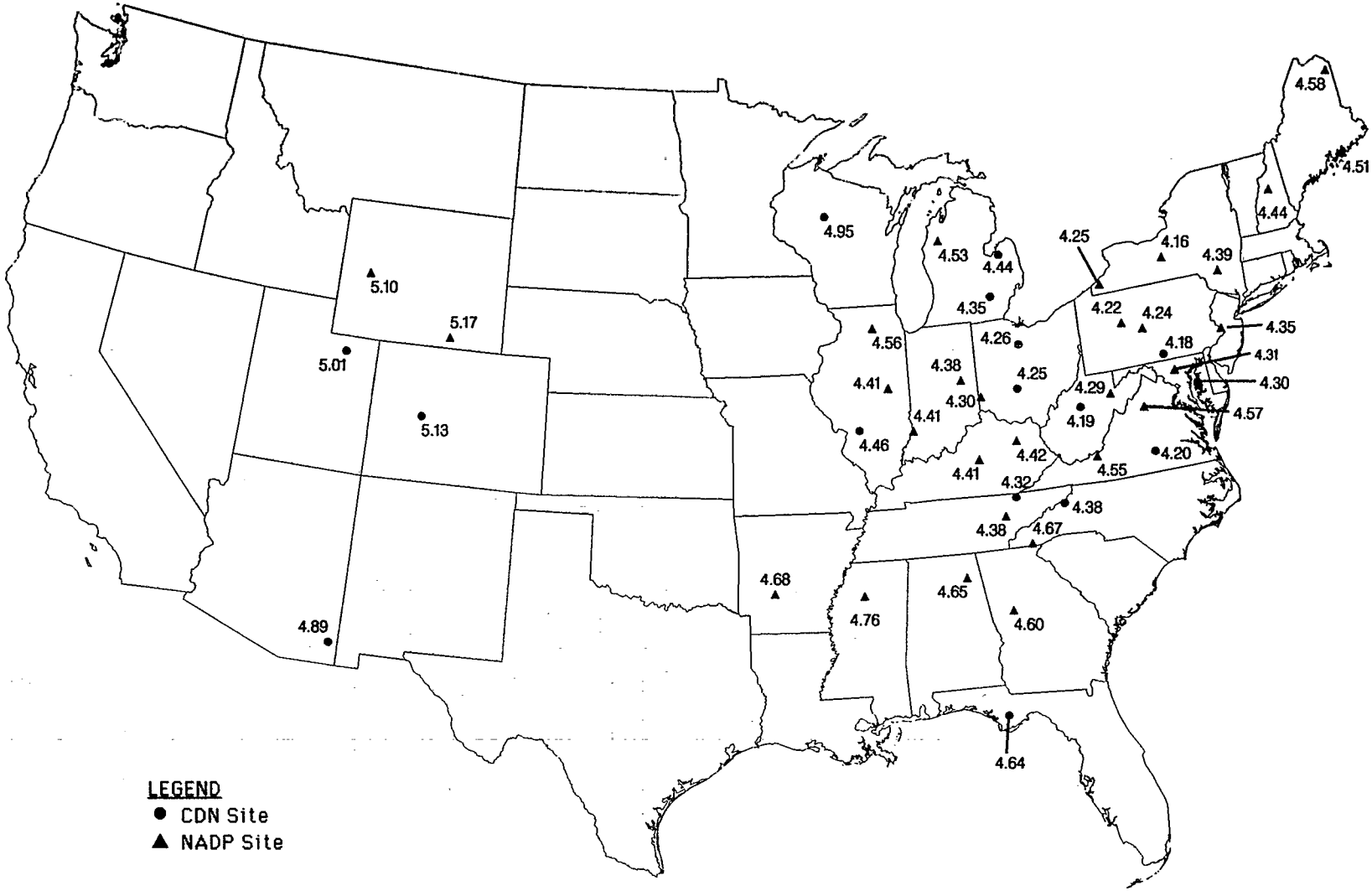


Figure 3-95. Annual average pH values for 1990 for the combined CDN/NADP database

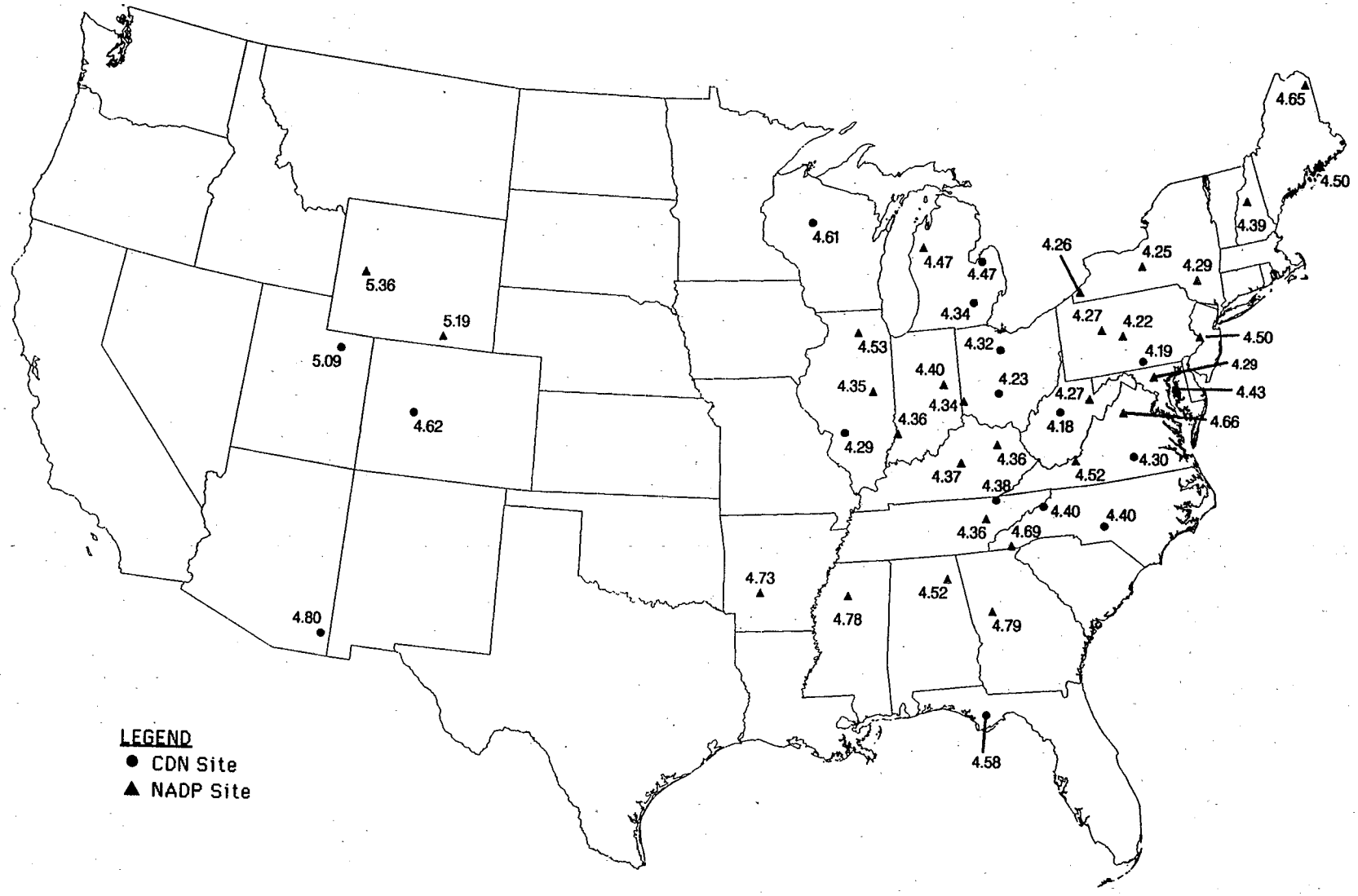


Figure 3-96. Annual average pH values for 1992 for the combined CDN/NADP database

Figure 3-97. Annual average pH values for 1994 for the combined CDN/NADP database

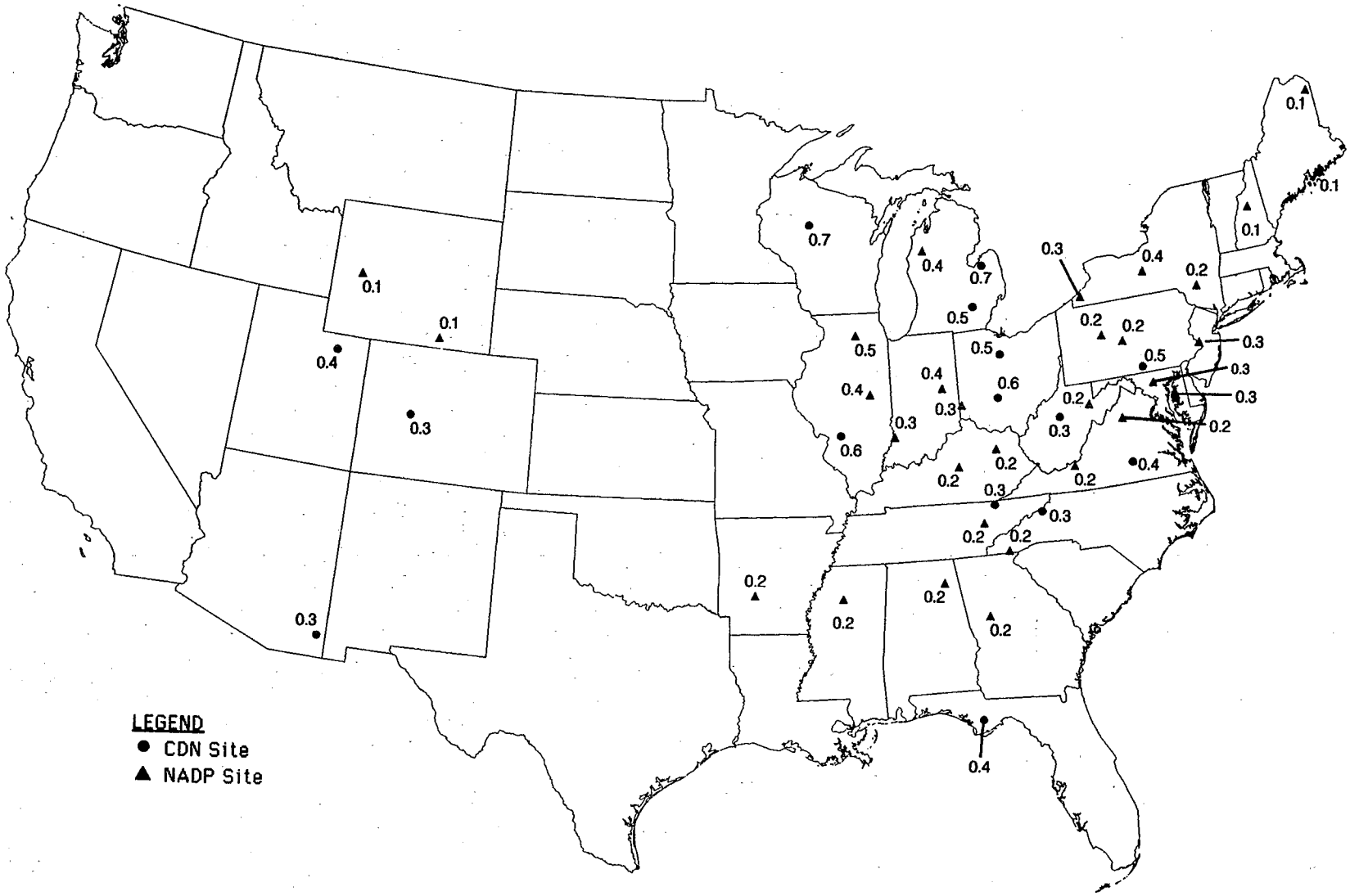


Figure 3-98. Annual average NH_4^+ concentrations (mg/L) for 1990 for the combined CDN/NADP database

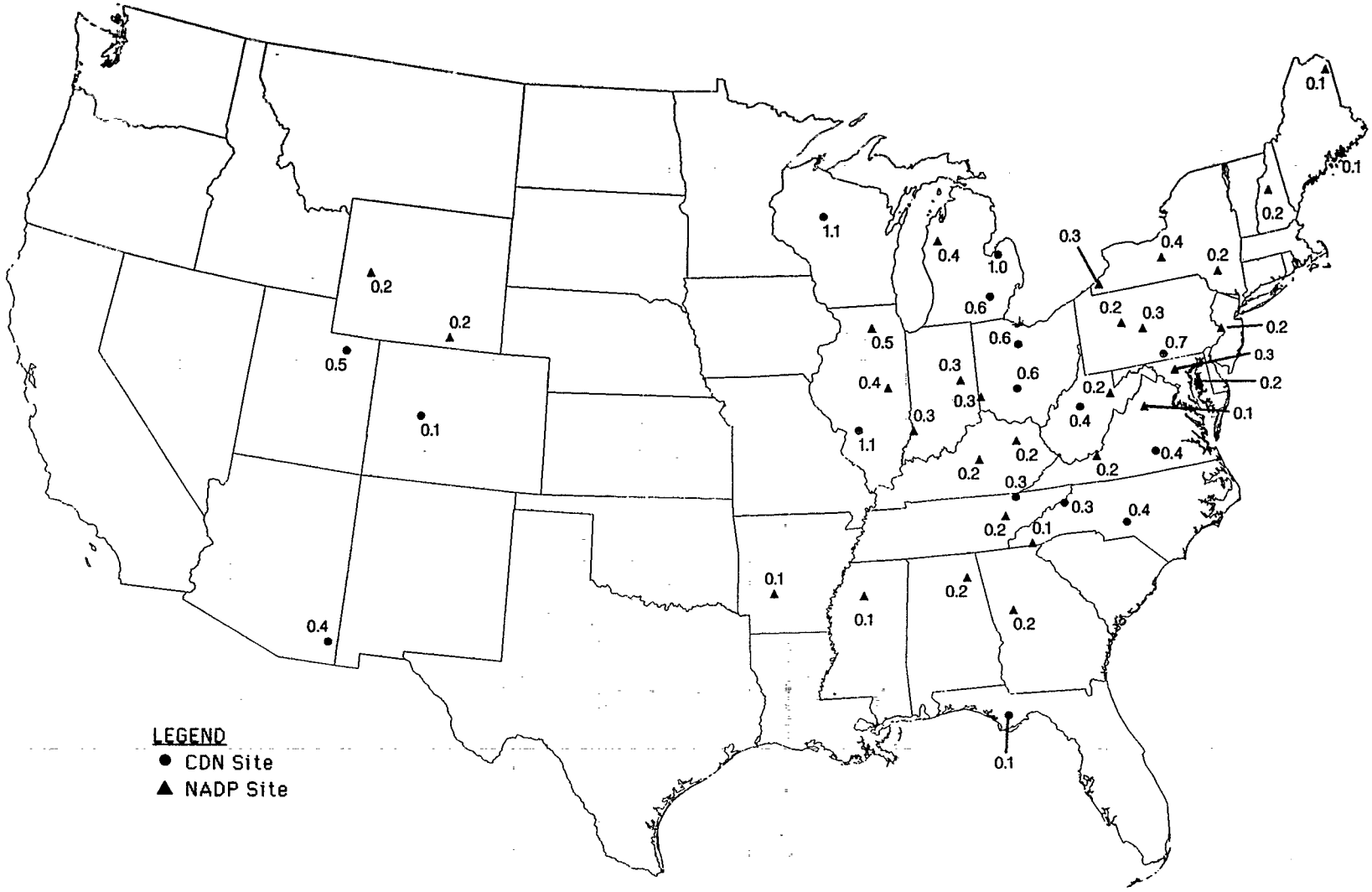


Figure 3-99. Annual average NH_4^+ concentrations (mg/L) for 1992 for the combined CDN/NADP database

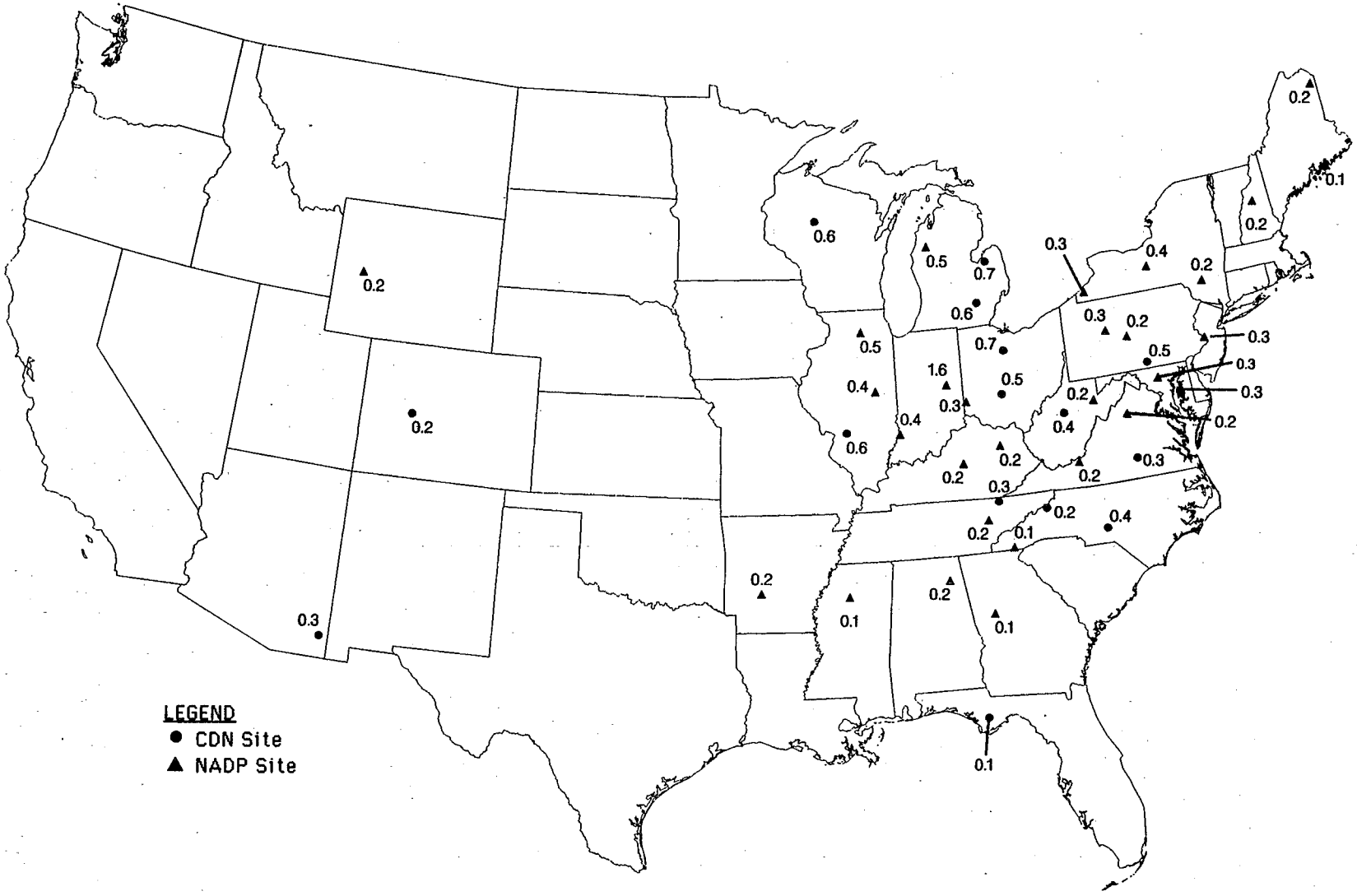


Figure 3-100. Annual average NH_4^+ concentrations (mg/L) for 1994 for the combined CDN/NADP database

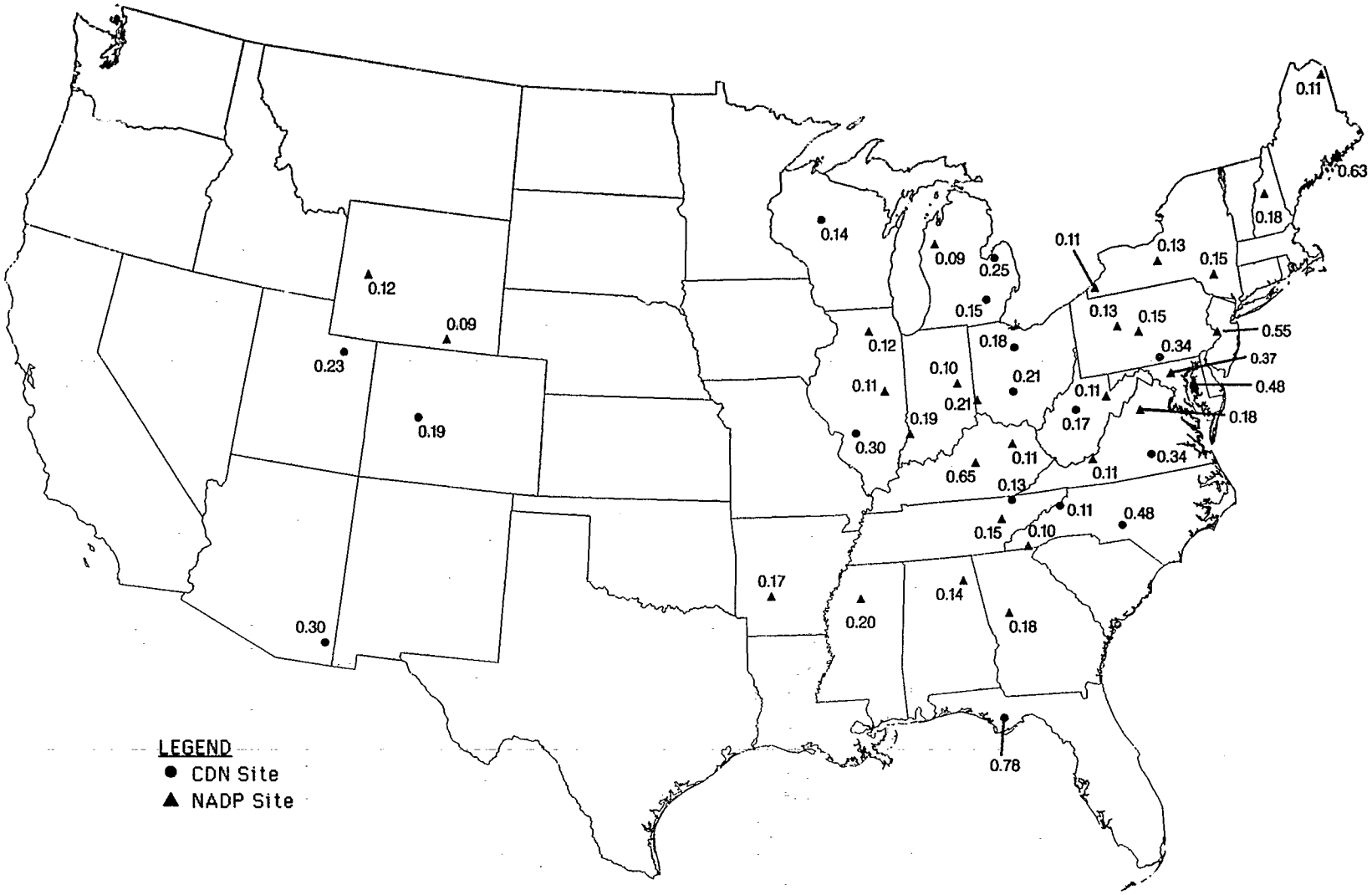


Figure 3-101. Annual average Cl^- concentrations (mg/L) for 1992 for the combined CDN/NADP database

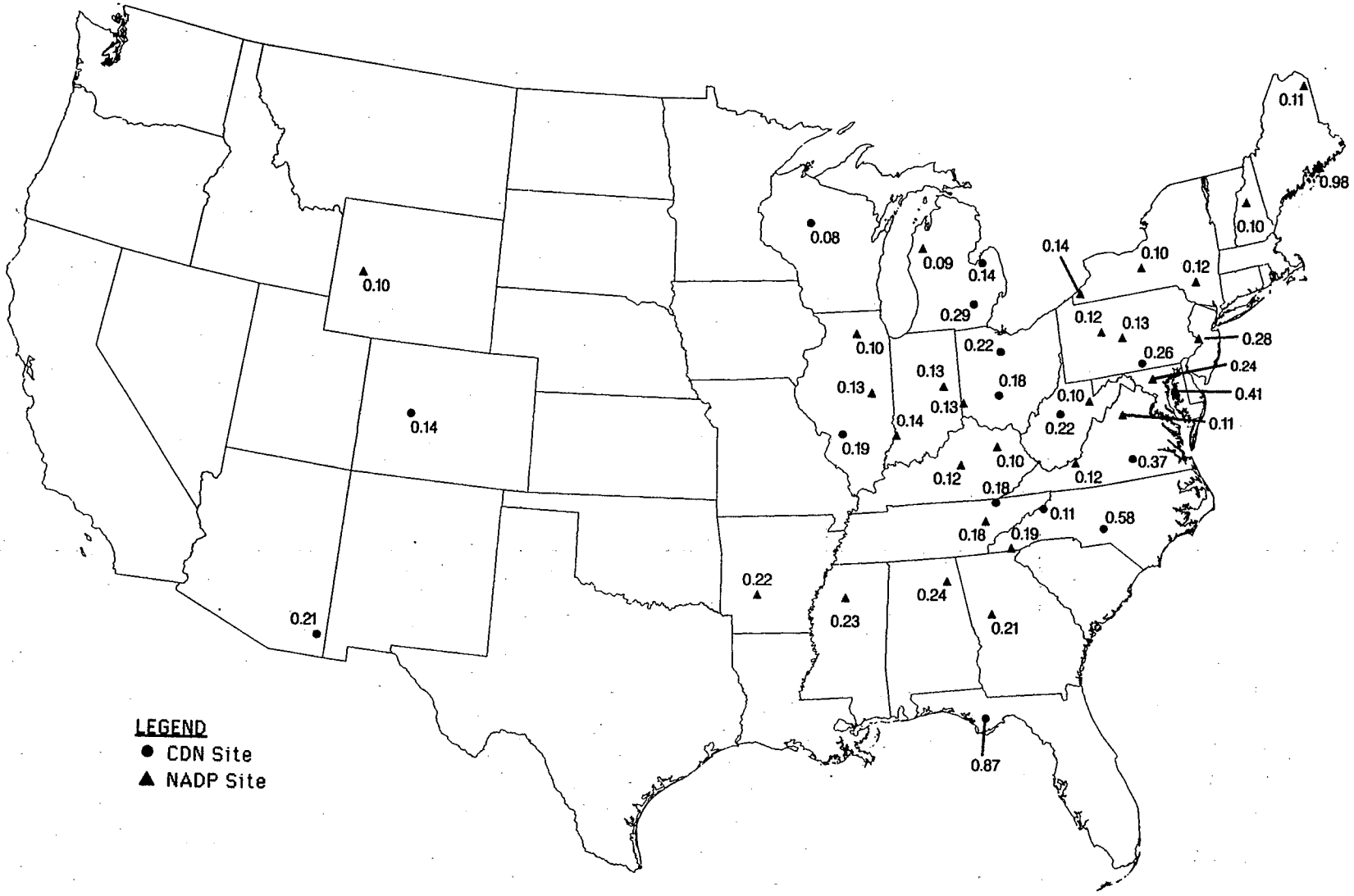


Figure 3-102. Annual average Cl^- concentrations (mg/L) for 1994 for the combined CDN/NADP database

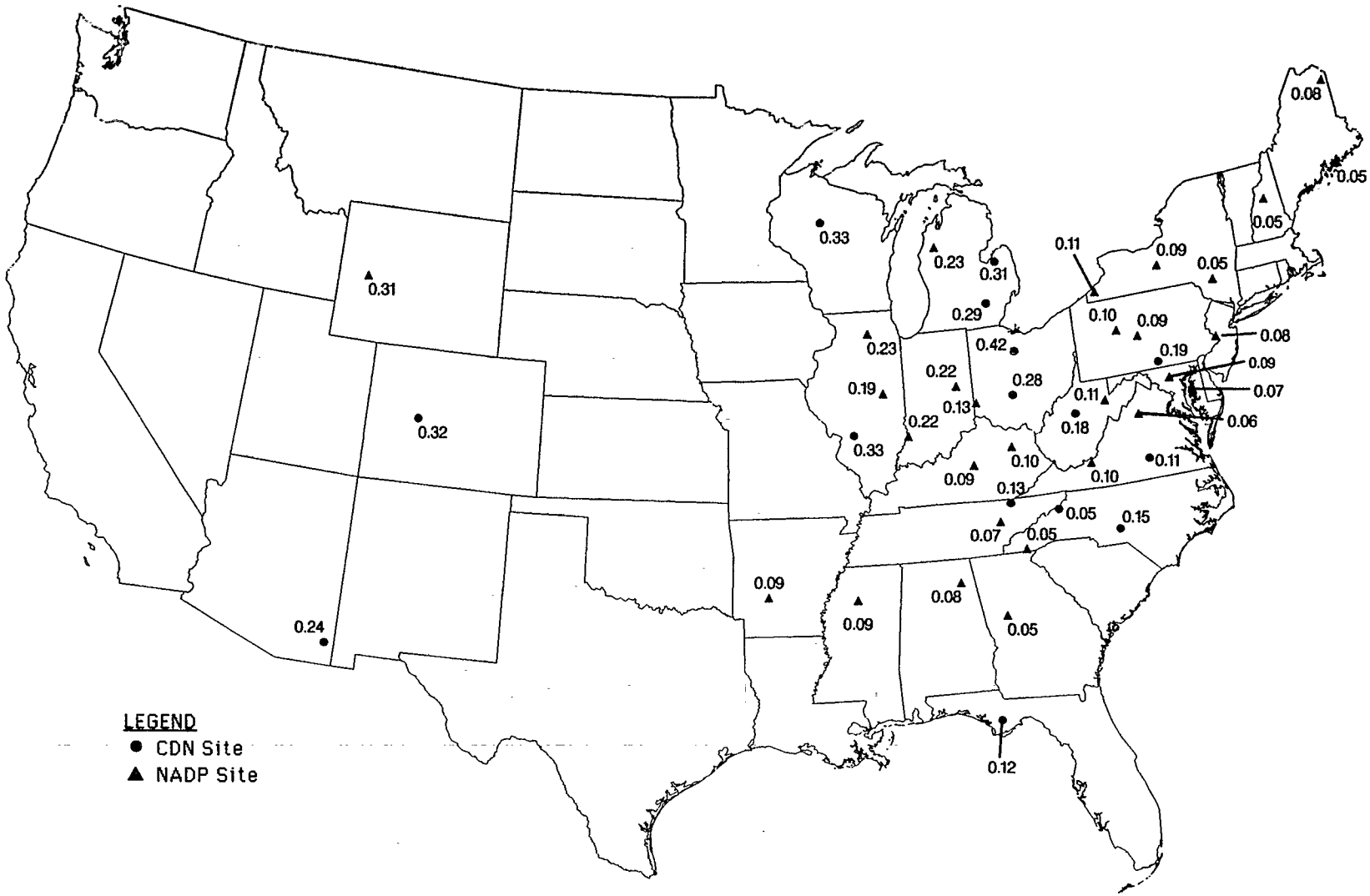


Figure 3-103. Annual average Ca^{2+} concentrations (mg/L) for 1994 for the combined CDN/NADP database

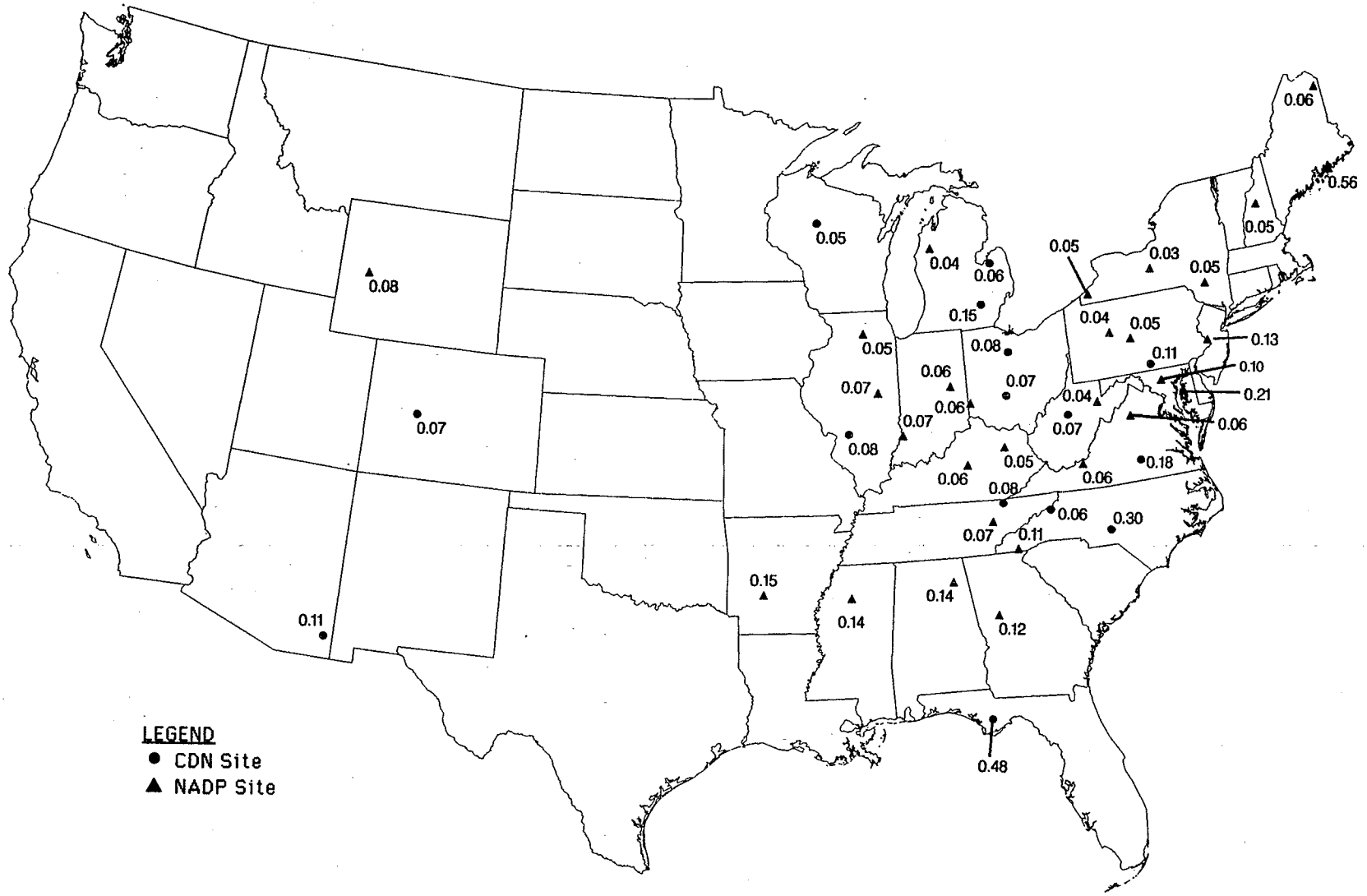


Figure 3-104. Annual average Na^+ concentrations (mg/L) for 1994 for the combined CDN/NADP database

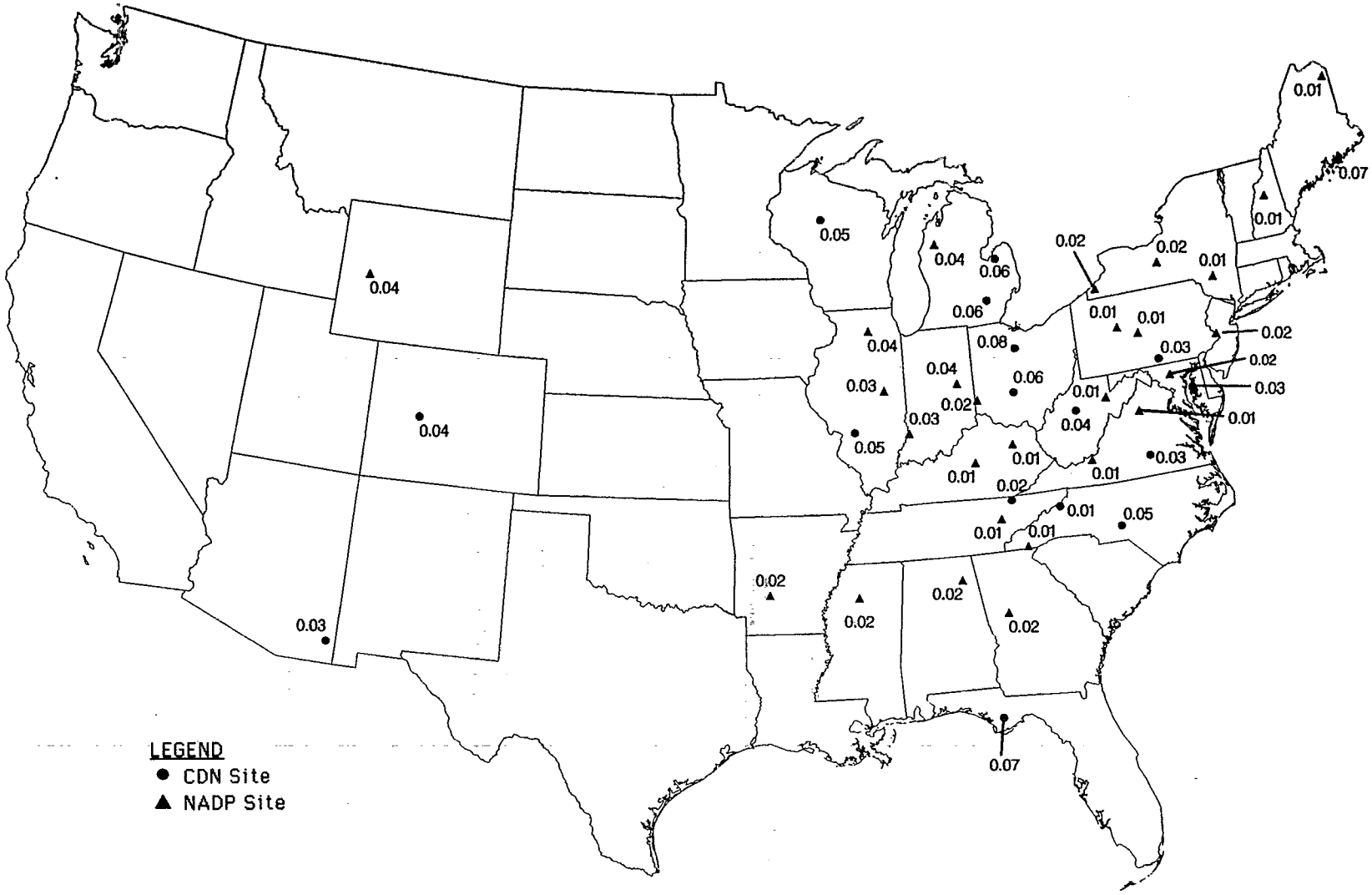


Figure 3-105. Annual average Mg^{2+} concentrations (mg/L) for 1994 for the combined CDN/NADP database

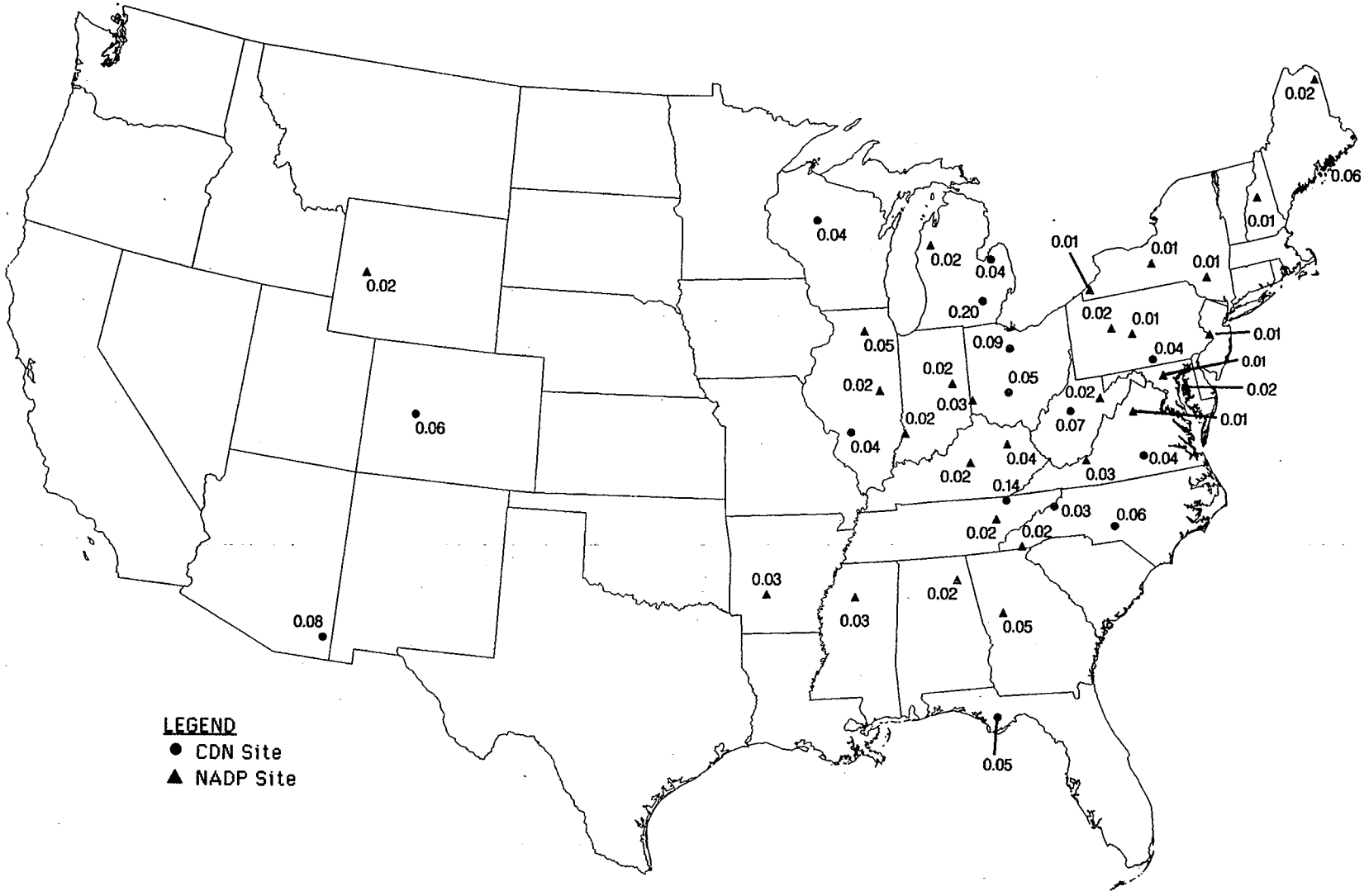


Figure 3-106. Annual average K^+ concentrations (mg/L) for 1994 for the combined CDN/NADP database

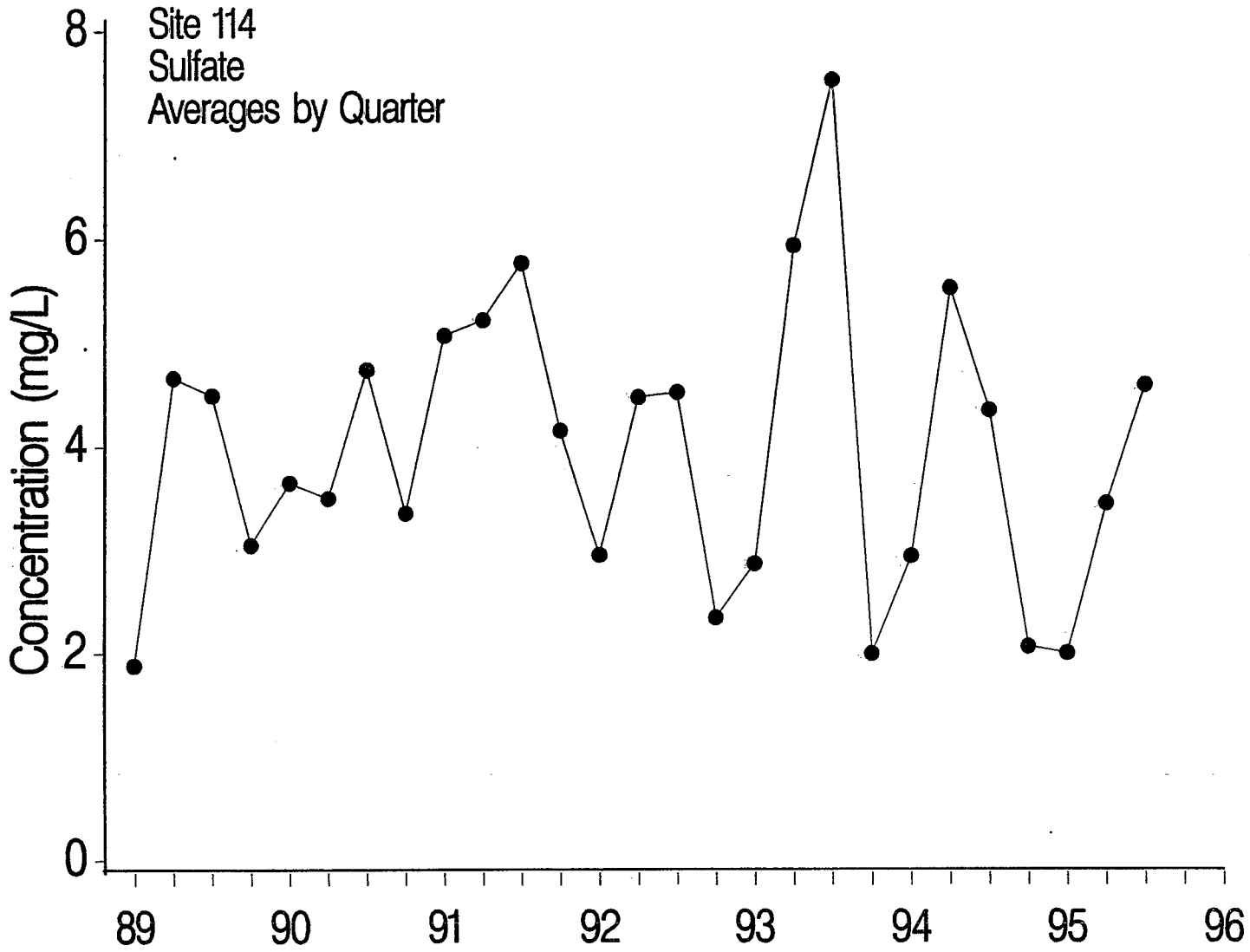


Figure 3-107. Time series plot of quarterly average precipitation concentrations of SO_4^{2-} for Site 114

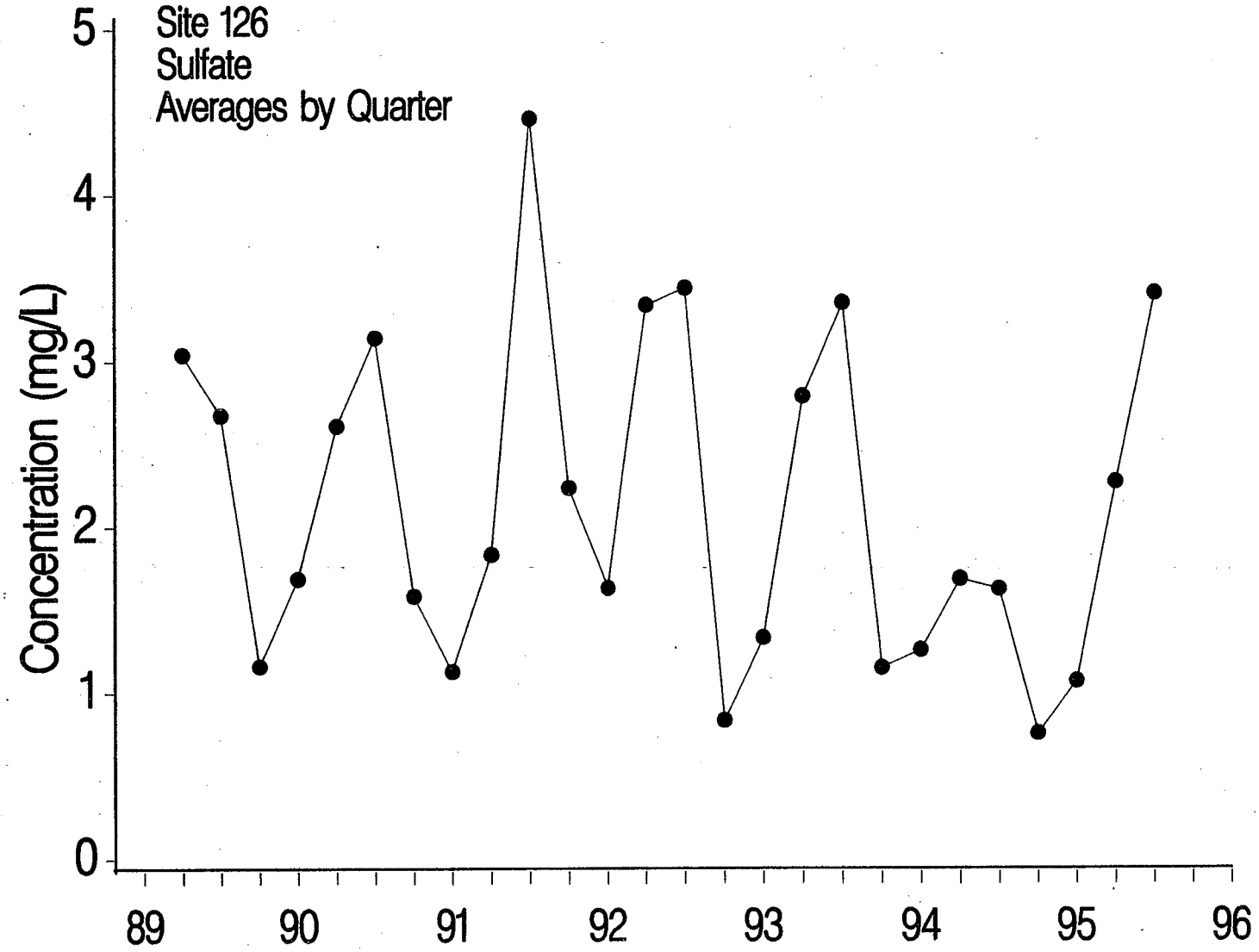


Figure 3-108. Time series plot of quarterly average precipitation concentrations of SO_4^{2-} for Site 126

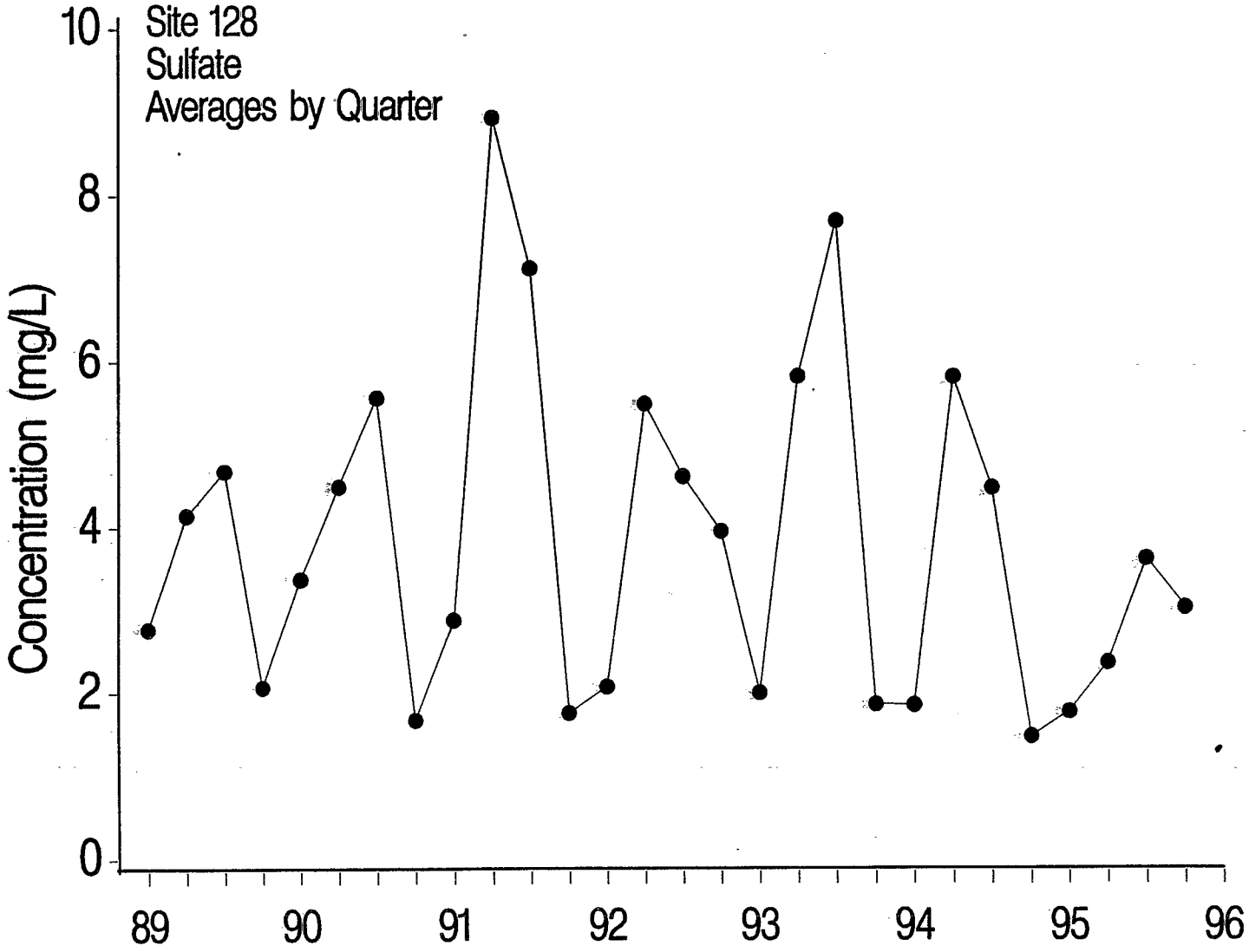


Figure 3-109. Time series plot of quarterly average precipitation concentrations of SO_4^{2-} for Site 128

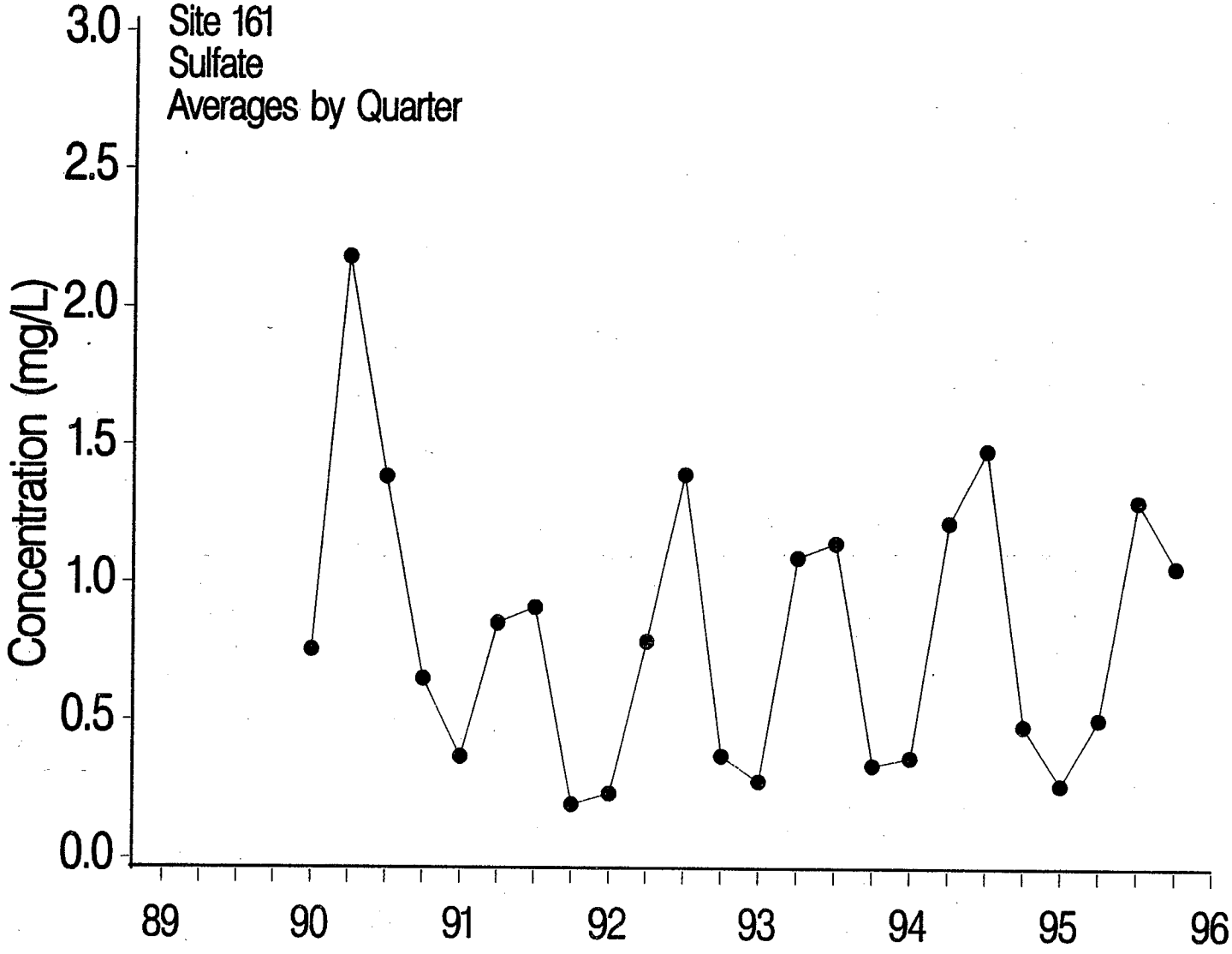


Figure 3-110. Time series plot of quarterly average precipitation concentrations of SO_4^{2-} for Site 161

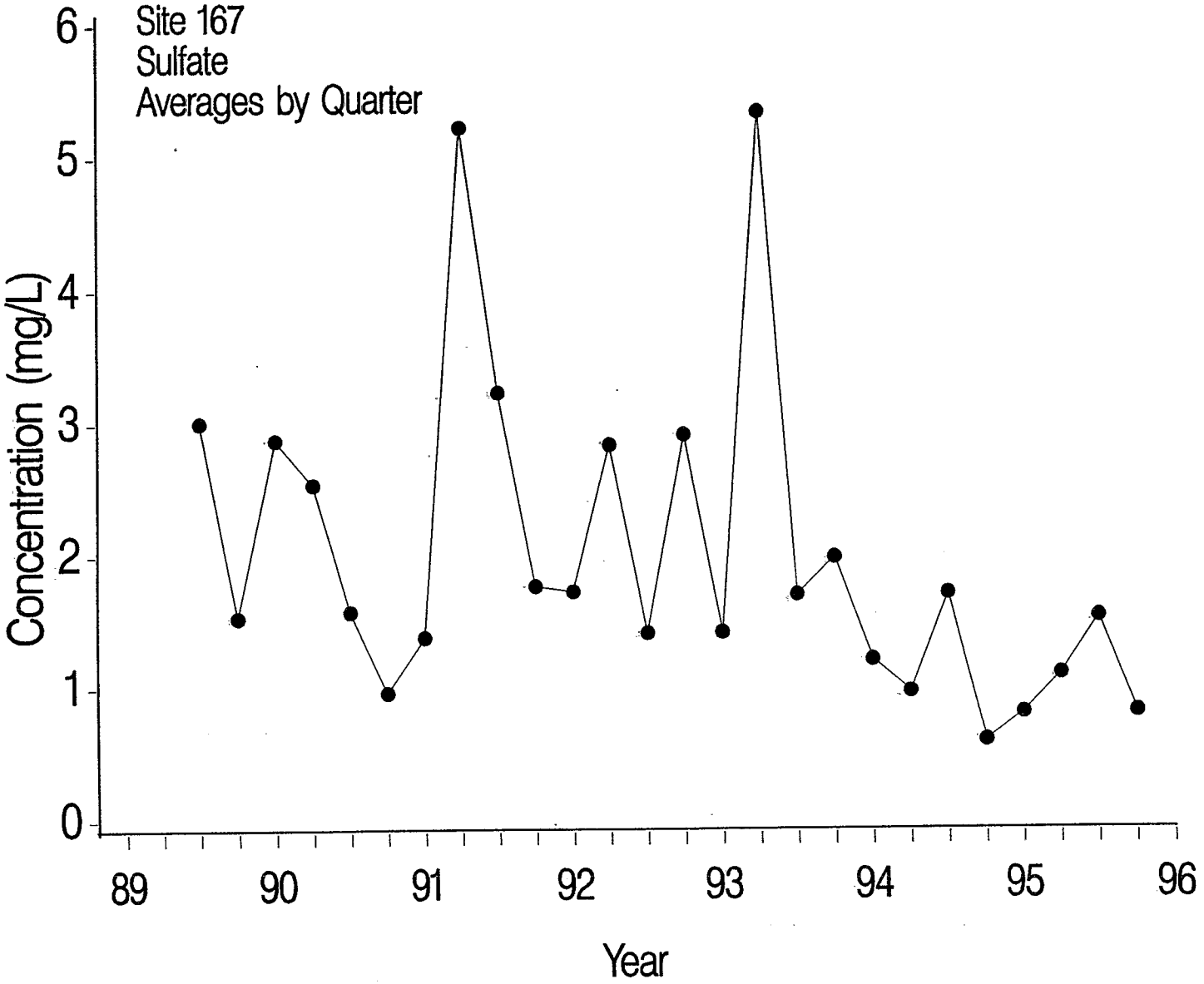


Figure 3-111. Time series plot of quarterly average precipitation concentrations of SO_4^{2-} for Site 167

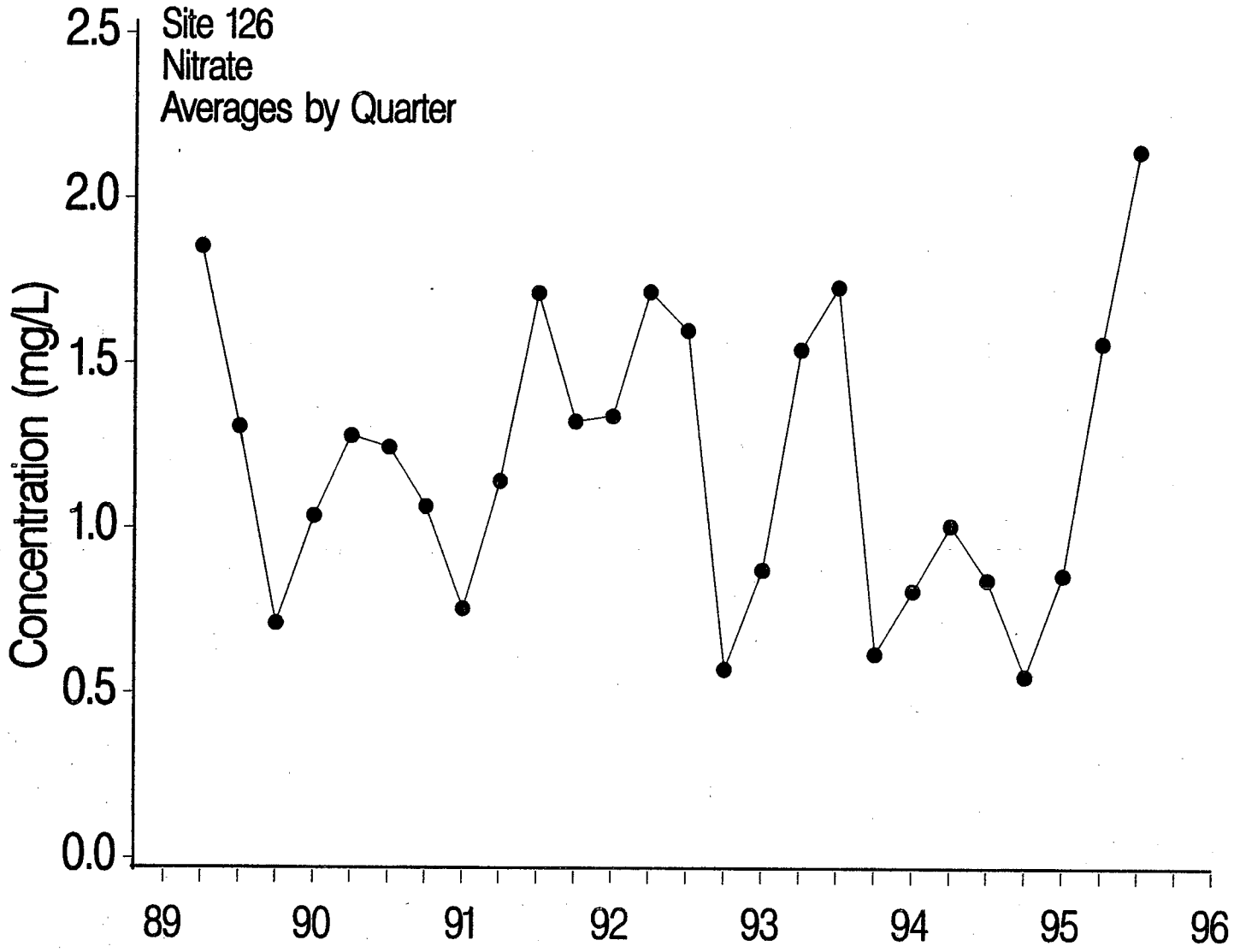


Figure 3-112. Time series plot of quarterly average precipitation concentrations of NO_3^- for Site 126

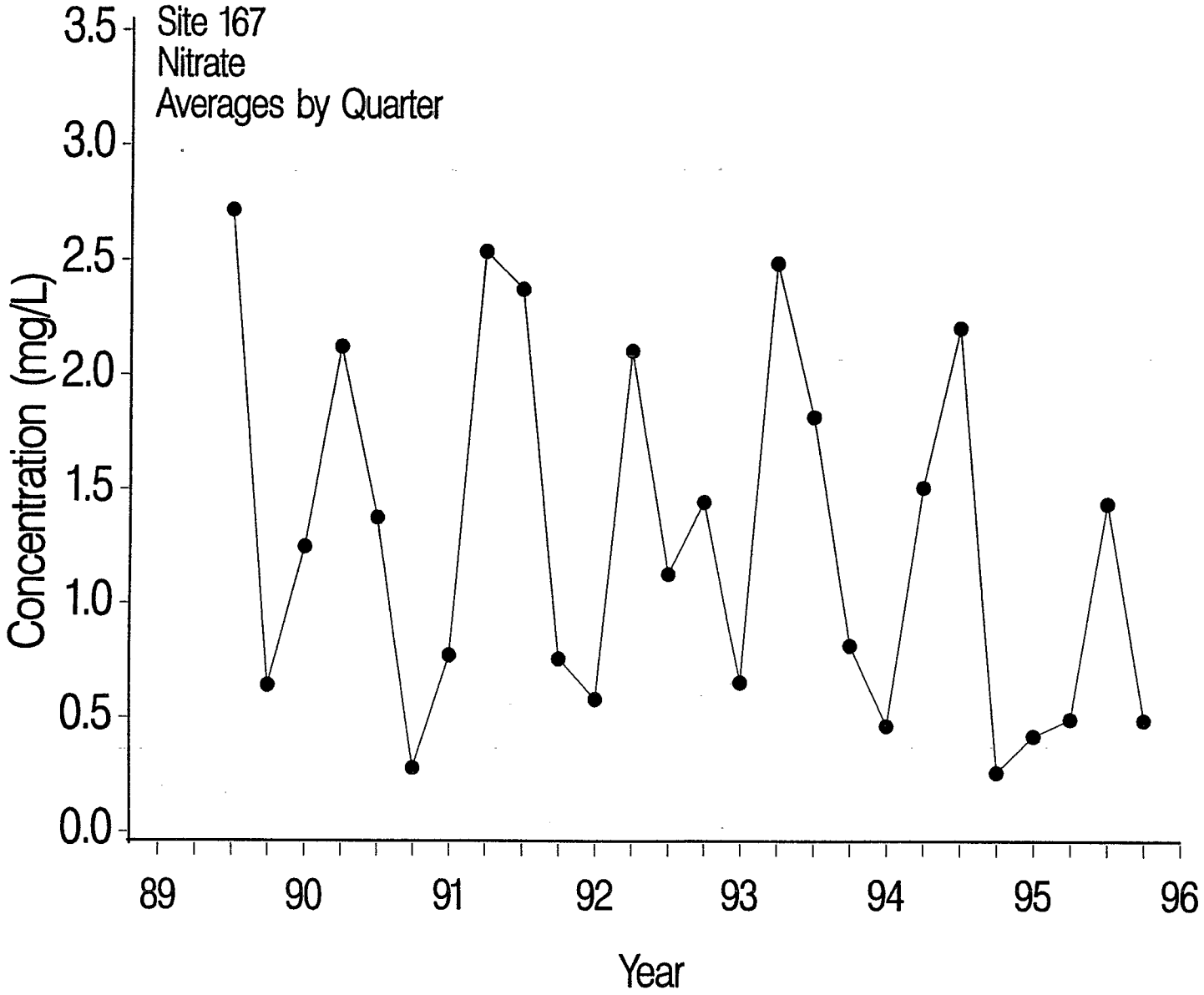


Figure 3-113. Time series plot of quarterly average precipitation concentrations of NO_3^- for Site 167

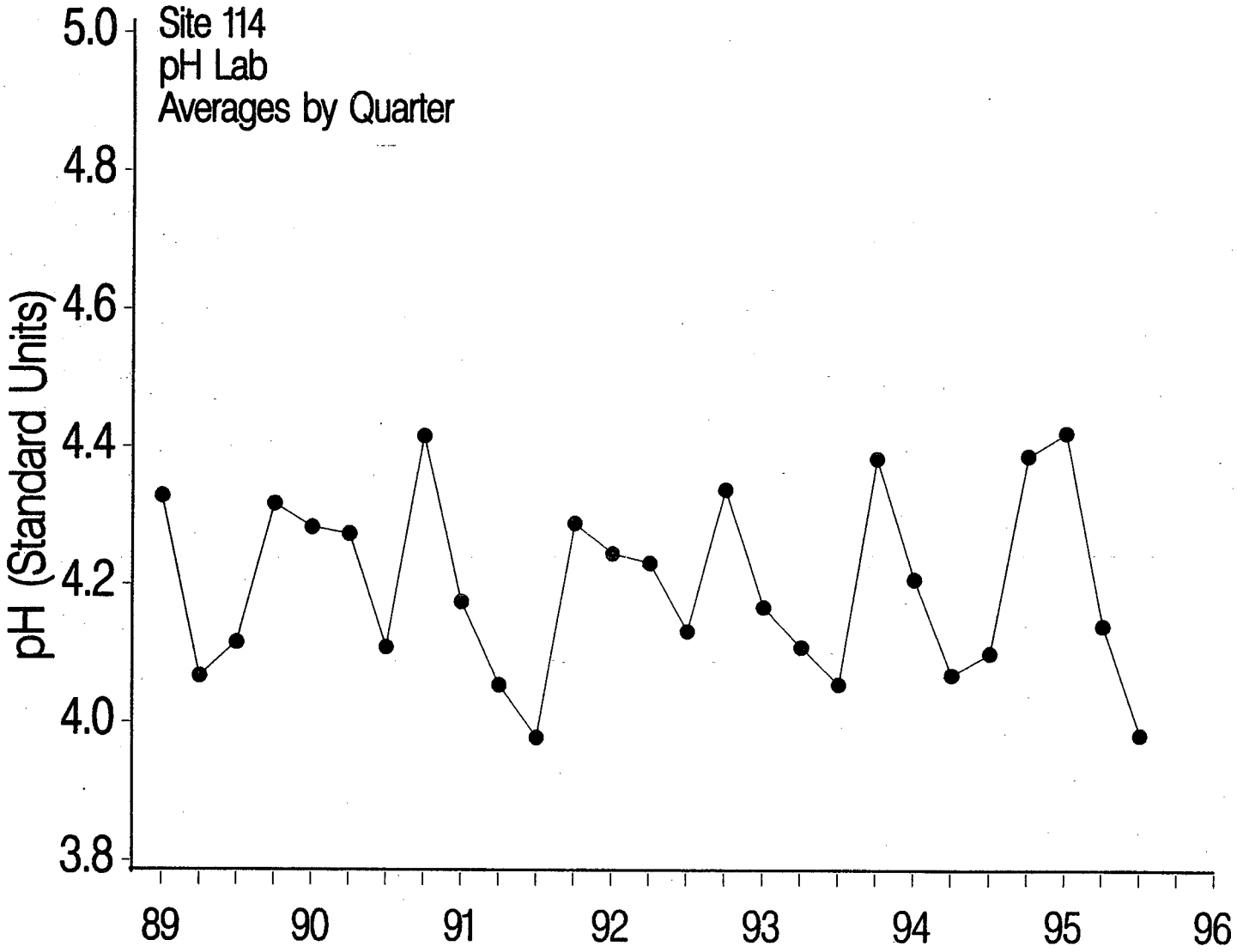


Figure 3-114. Time series plot of quarterly average values of pH for Site 114

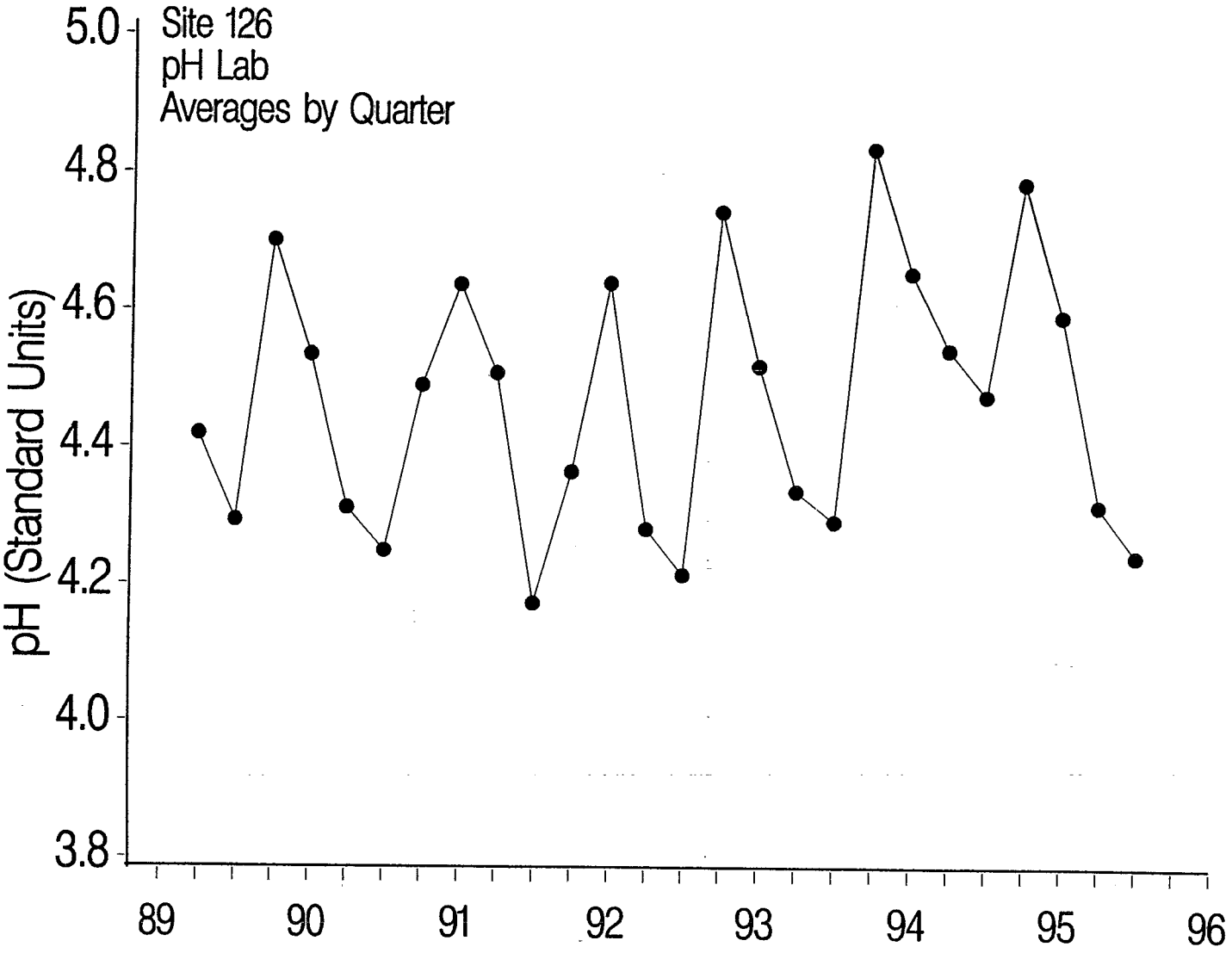


Figure 3-115. Time series plot of quarterly average values of pH for Site 126

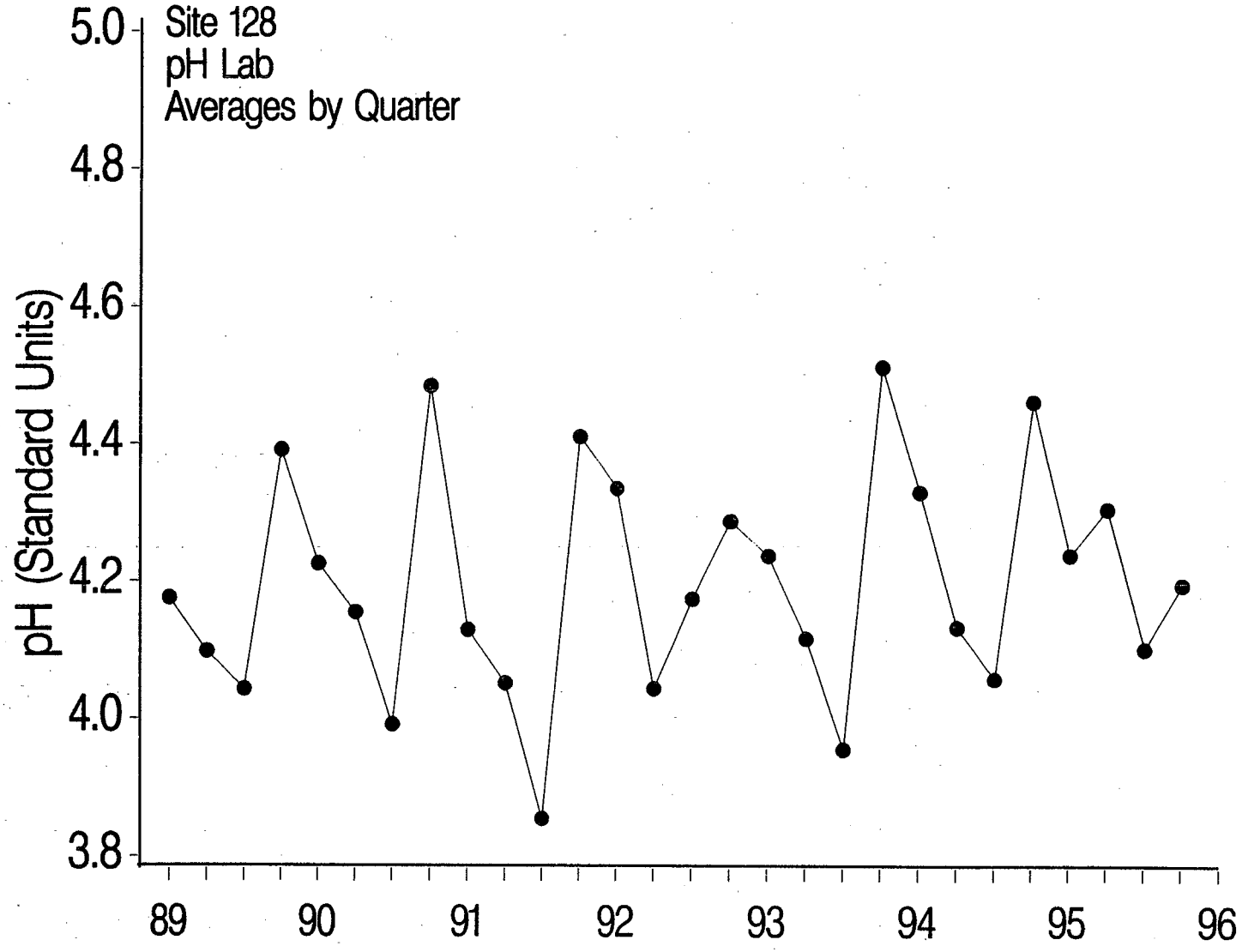


Figure 3-116. Time series plot of quarterly average values of pH for Site 128

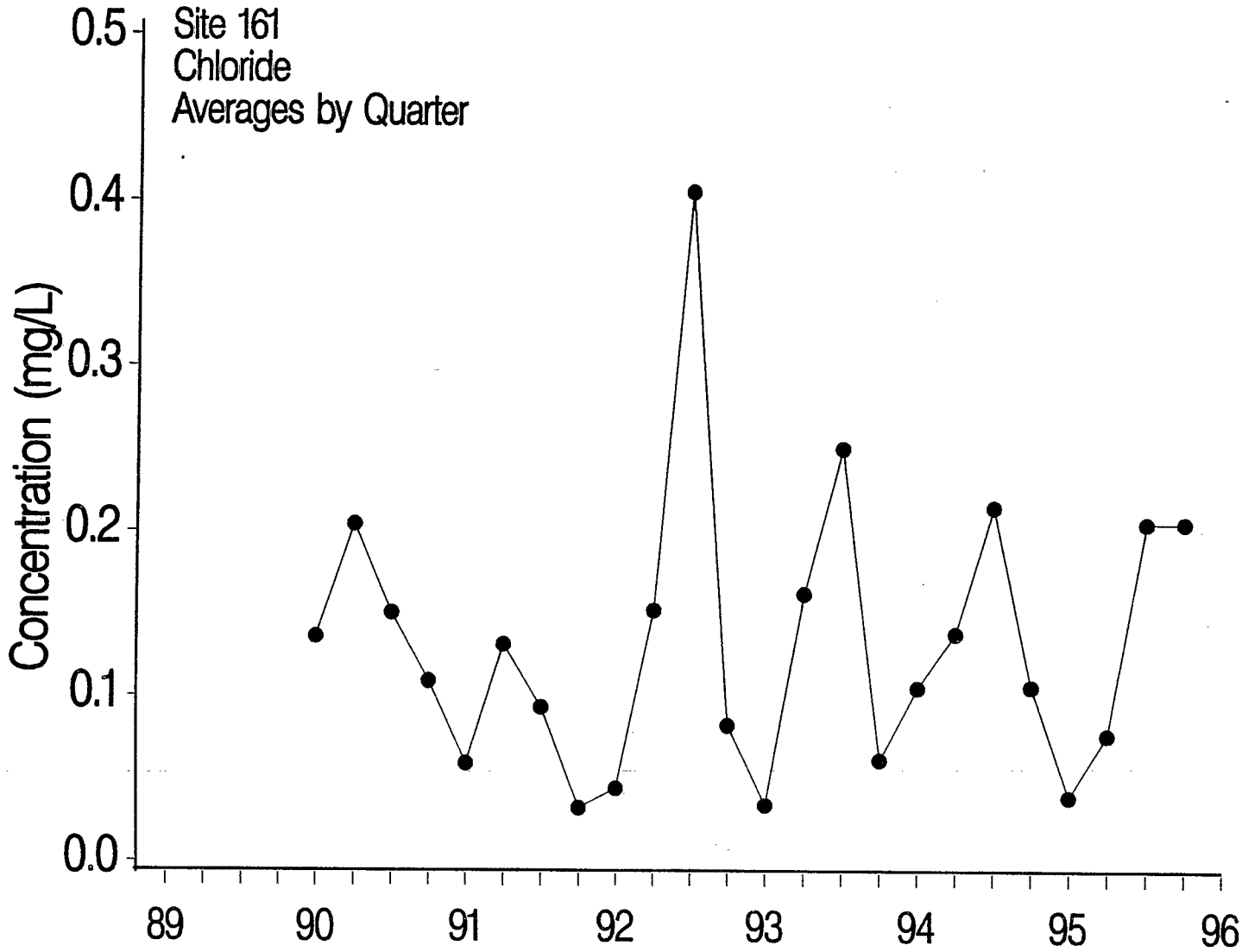


Figure 3-117. Time series plot of quarterly average precipitation concentrations of Cl^- for Site 126

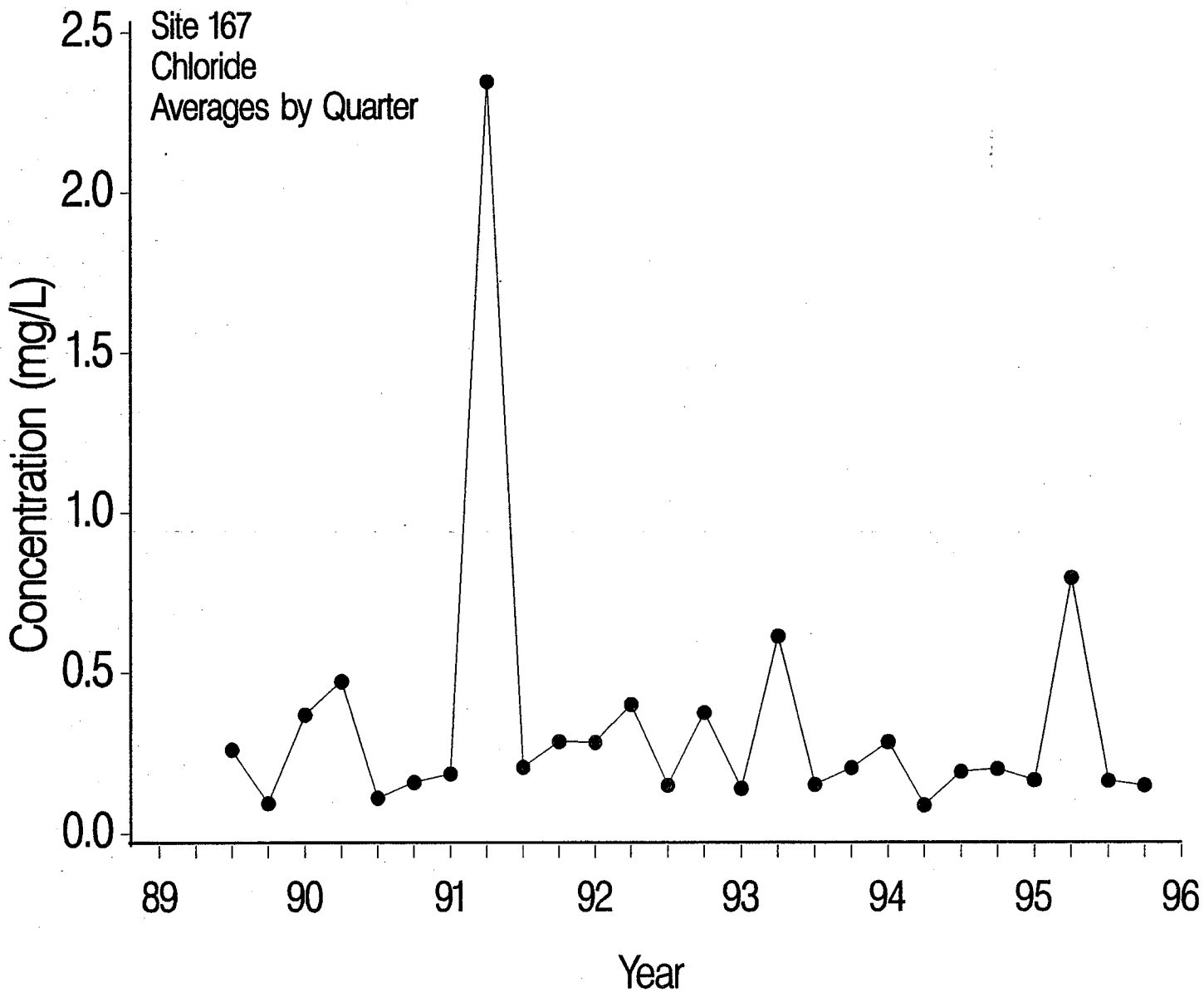


Figure 3-118. Time series plot of quarterly average precipitation concentrations of Cl^- for Site 128

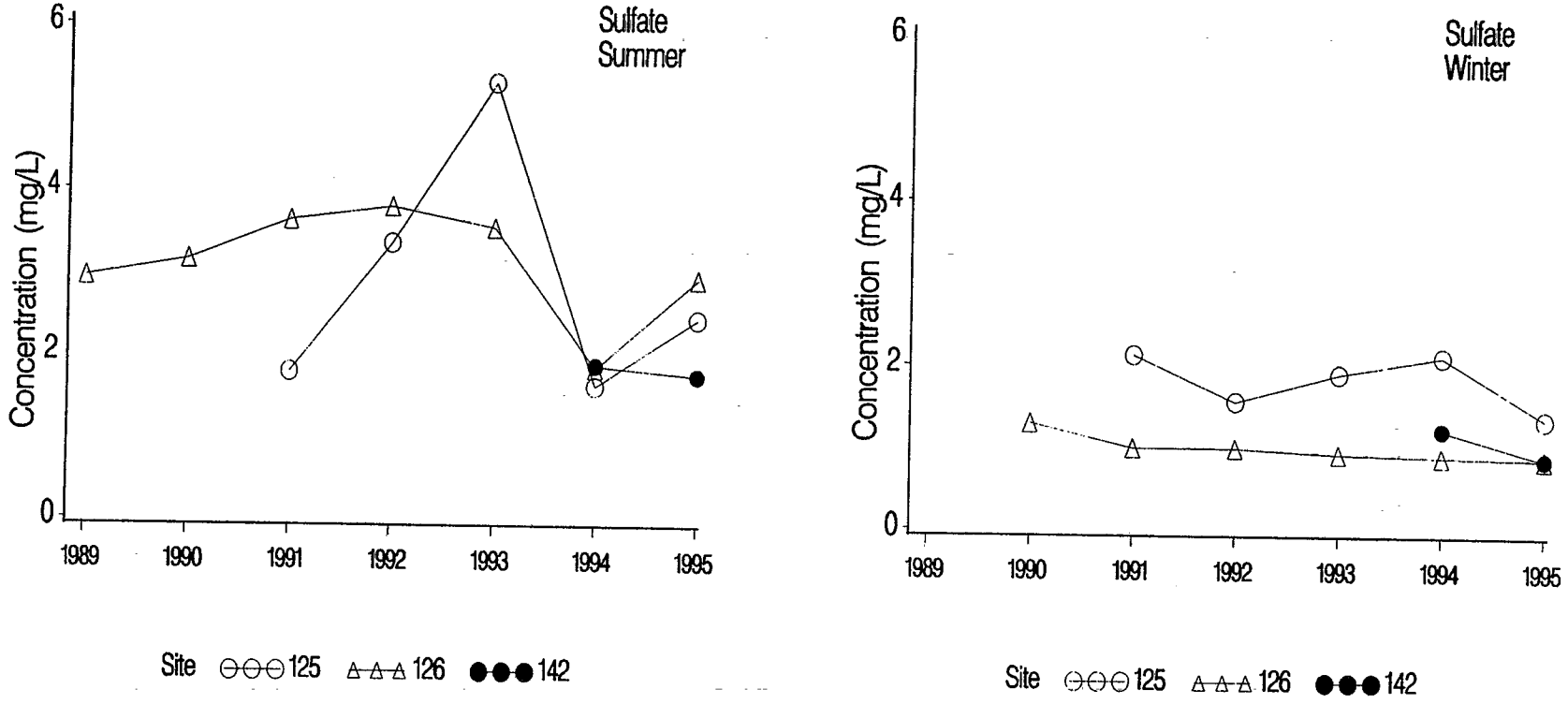


Figure 3-119. Seasonal (summer vs. winter) variability of SO_4^{2-} (mg/L) for three eastern sites (125, 126, and 142)

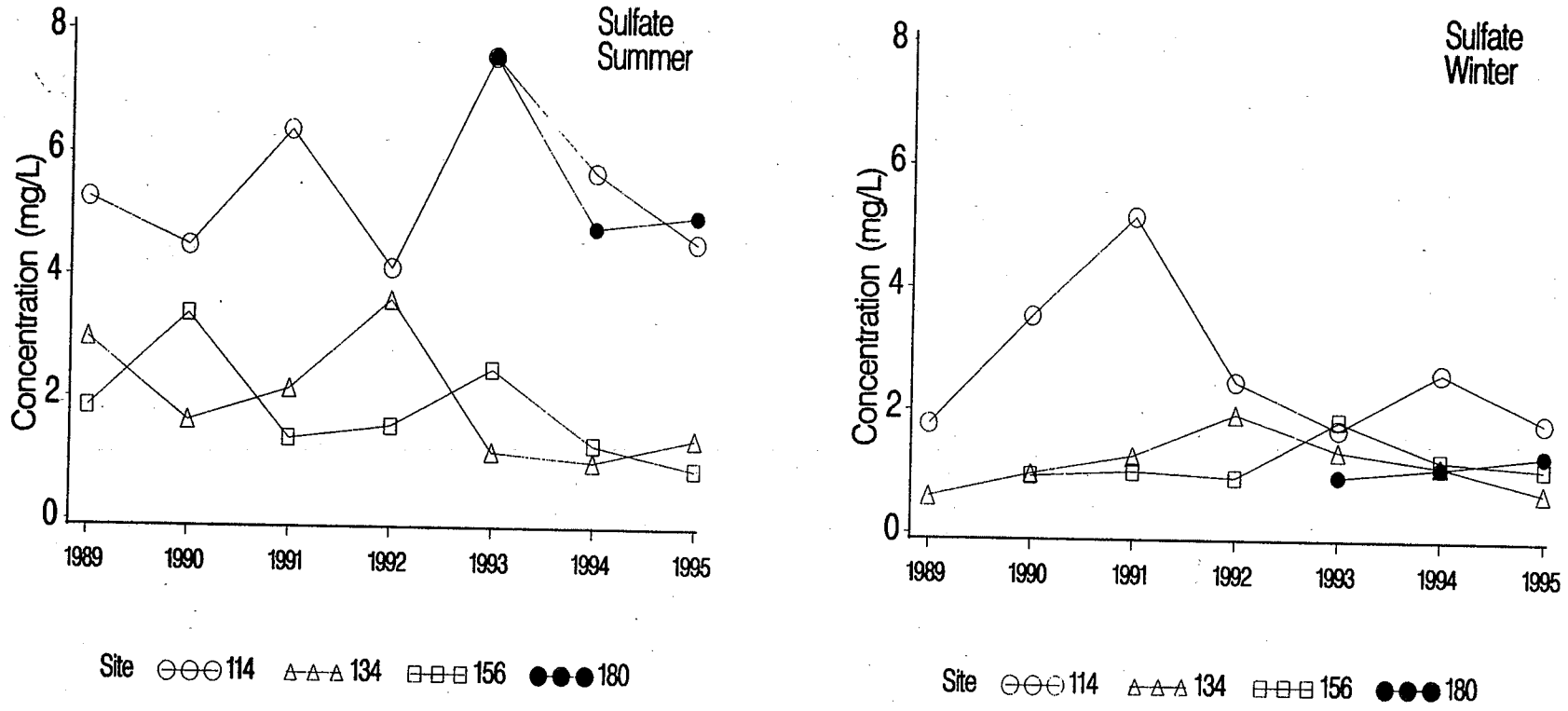


Figure 3-120. Seasonal (summer vs. winter) variability of SO_4^{2-} (mg/L) for four eastern sites (114, 134, 156, and 180)

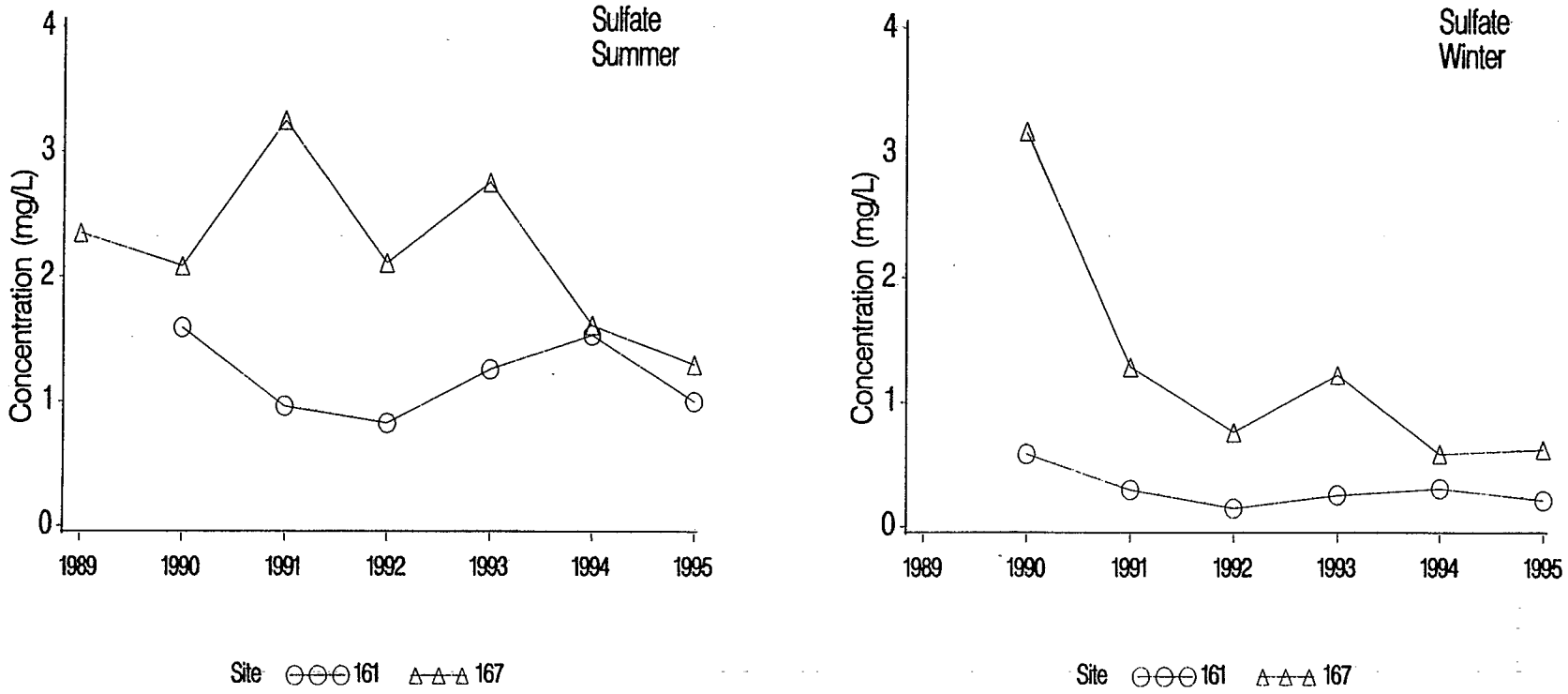


Figure 3-121. Seasonal (summer vs. winter) variability of SO_4^{2-} (mg/L) for two western sites (161 and 167)

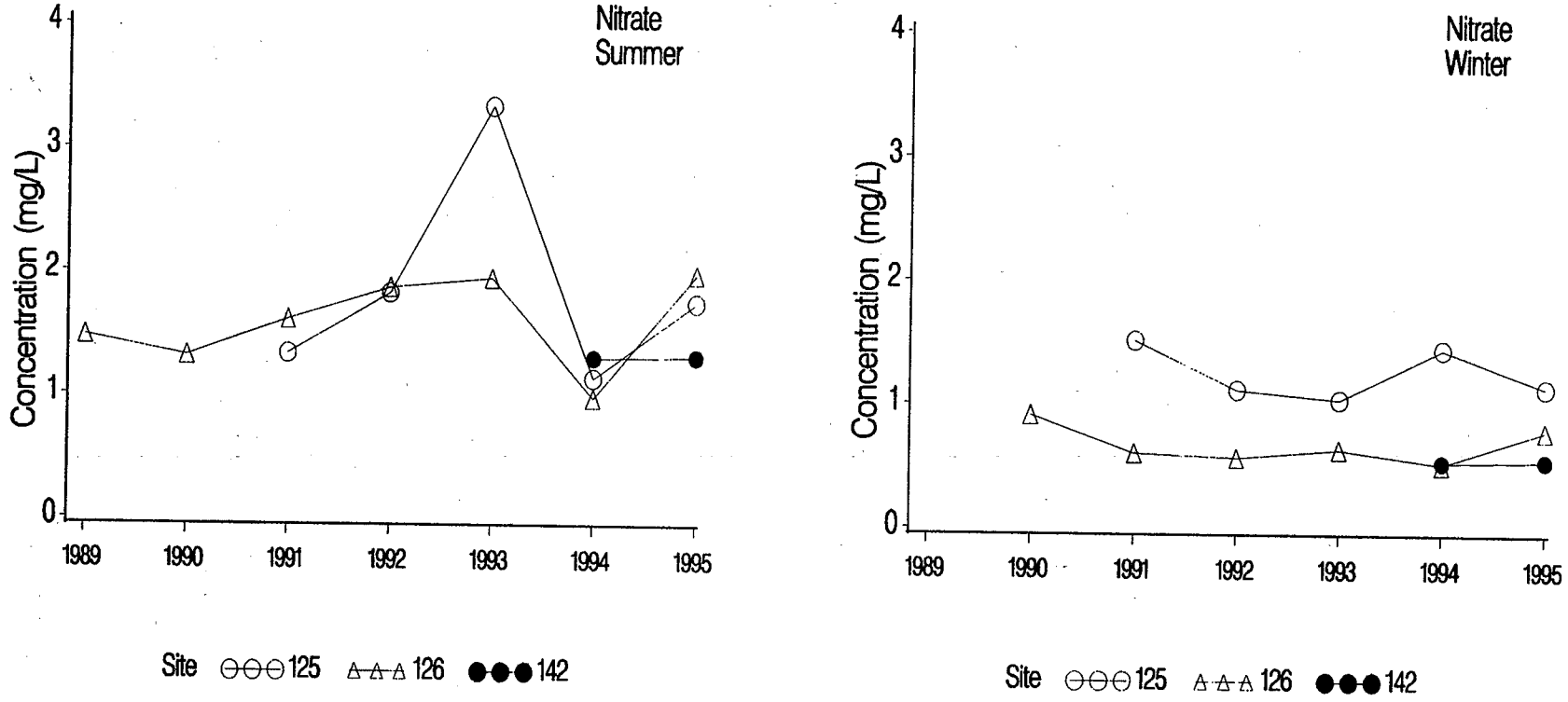


Figure 3-122. Seasonal (summer vs. winter) variability of NO_3^- (mg/L) for three eastern sites (125, 126, and 142)

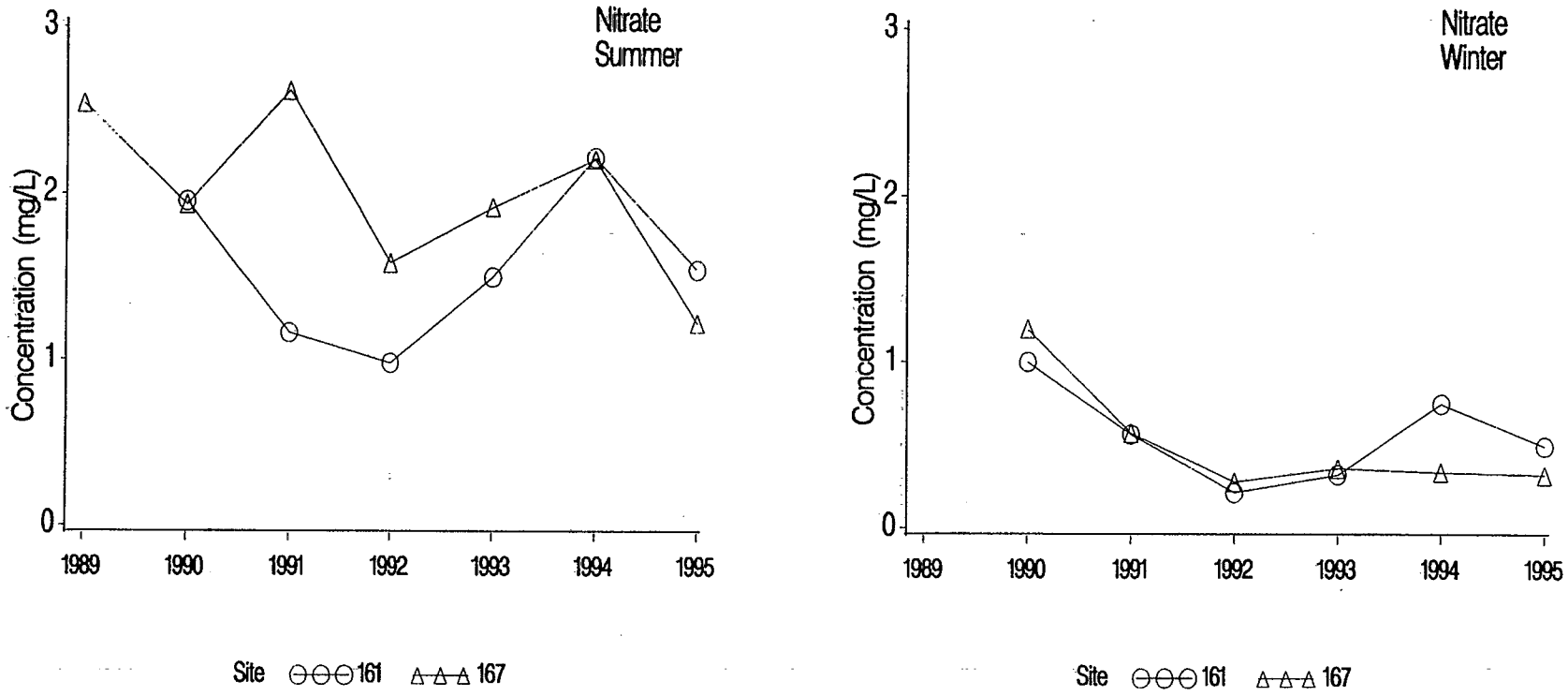


Figure 3-123. Seasonal (summer vs. winter) variability of NO_3^- (mg/L) for two western sites (161 and 167)

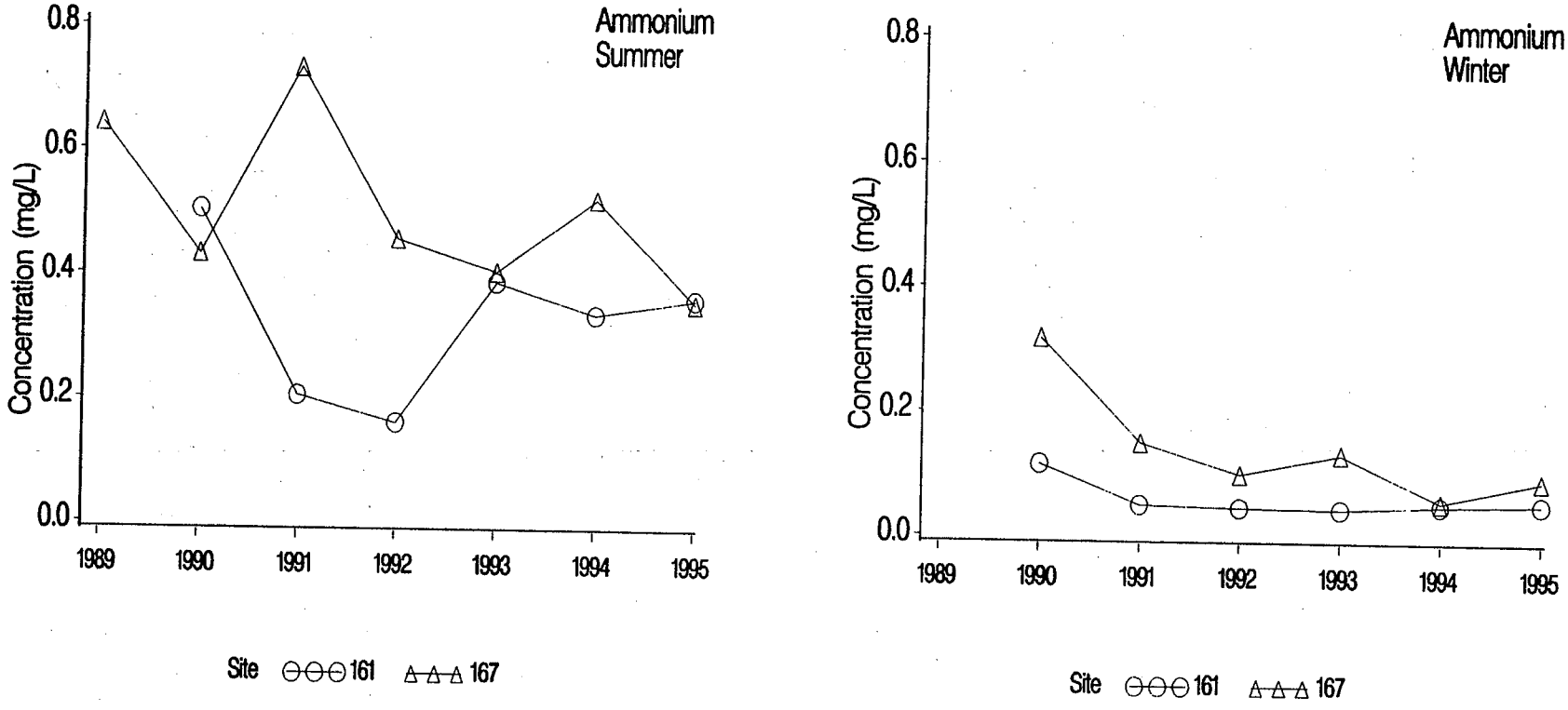


Figure 3-124. Seasonal (summer vs. winter) variability of NH_4^+ (mg/L) for two western sites (161 and 167)

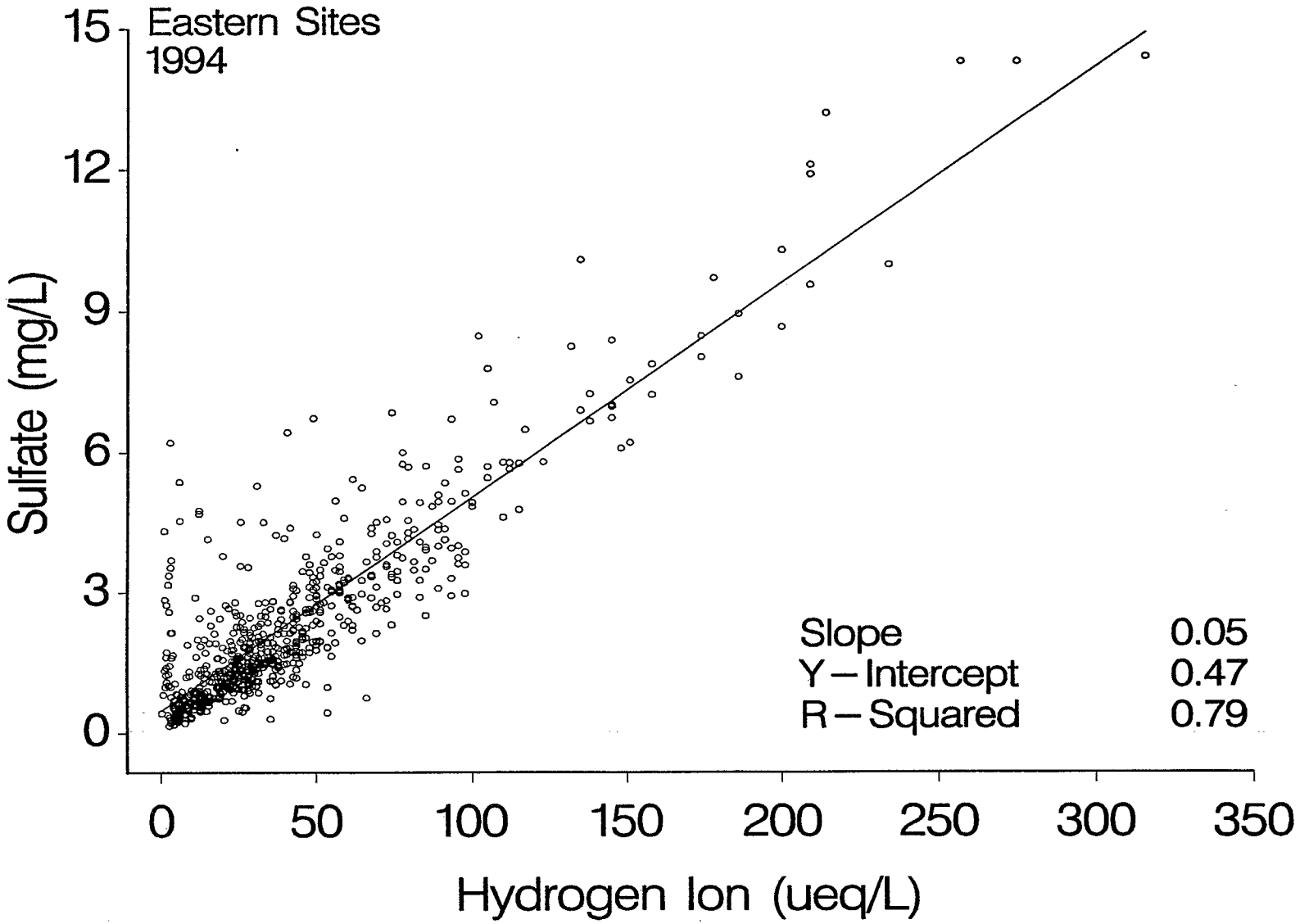


Figure 3-125. Linear regression of SO_4^{2-} concentrations against H^+ concentrations in 1994 for all eastern CDN sites combined

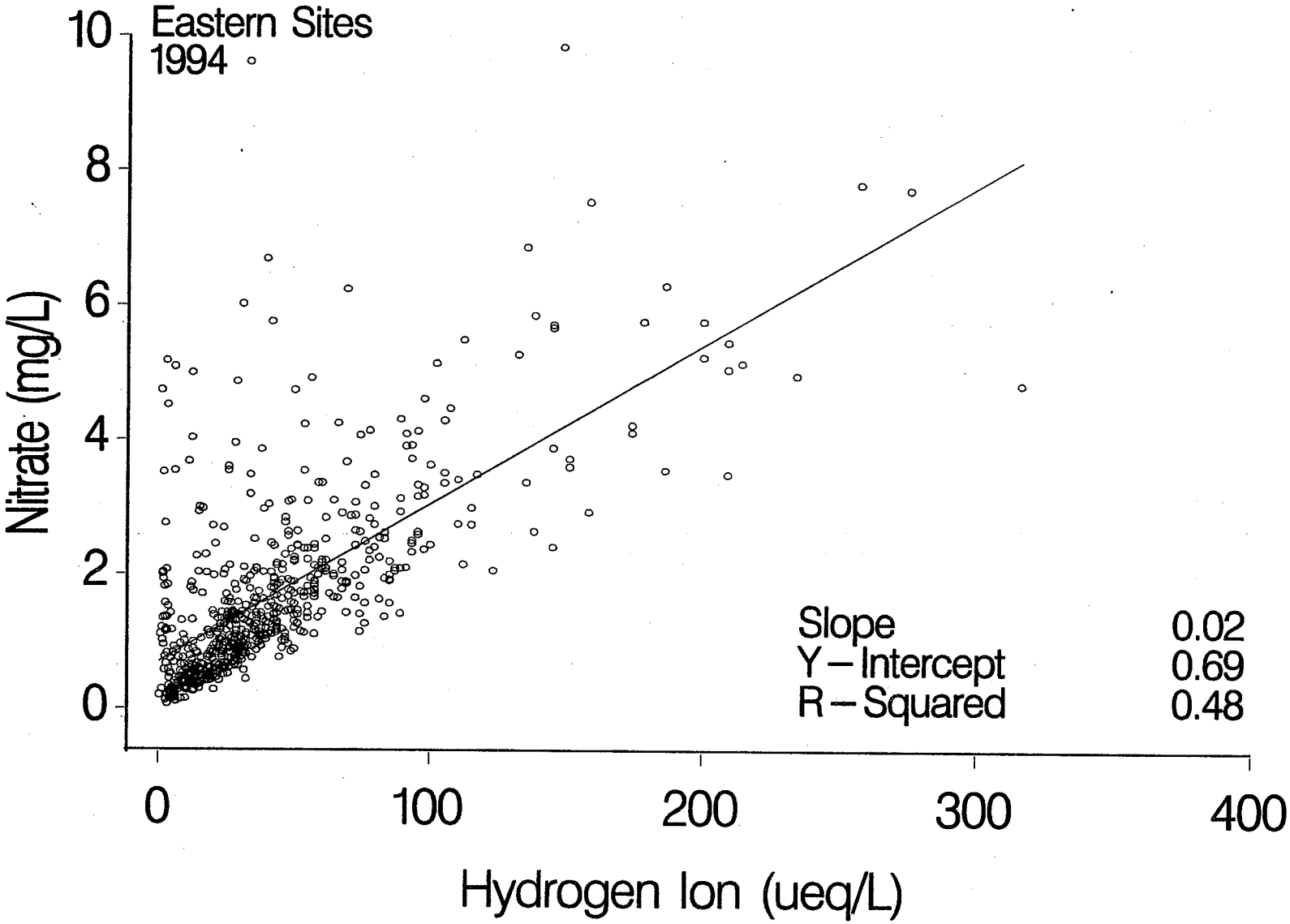


Figure 3-126. Linear regression of NO_3^- concentrations against H^+ concentrations in 1994 for all eastern CDN sites combined

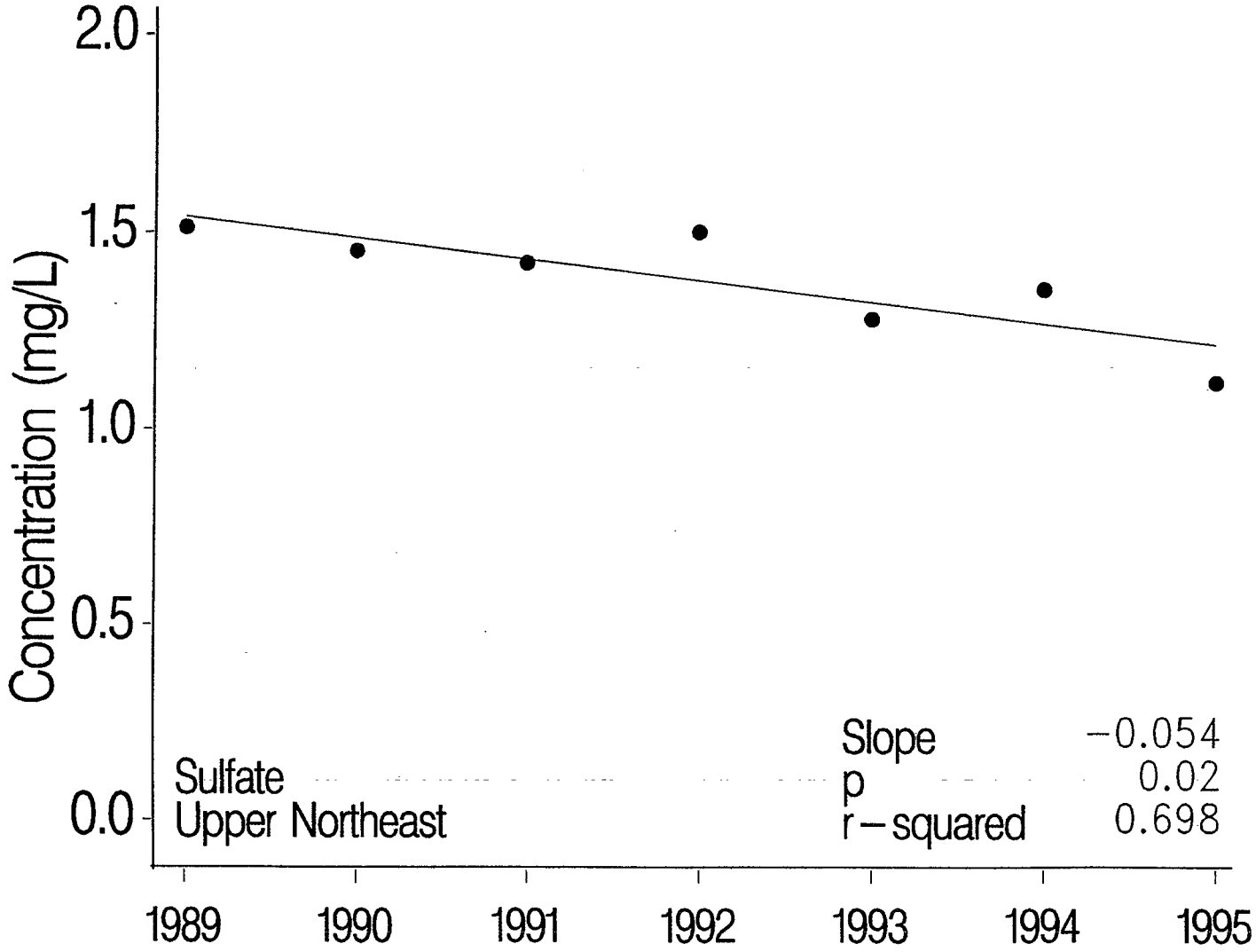


Figure 3-127. Linear regression analysis of SO_4^{2-} concentrations versus year for the upper northeast subregion (combined CDN/NADP data)

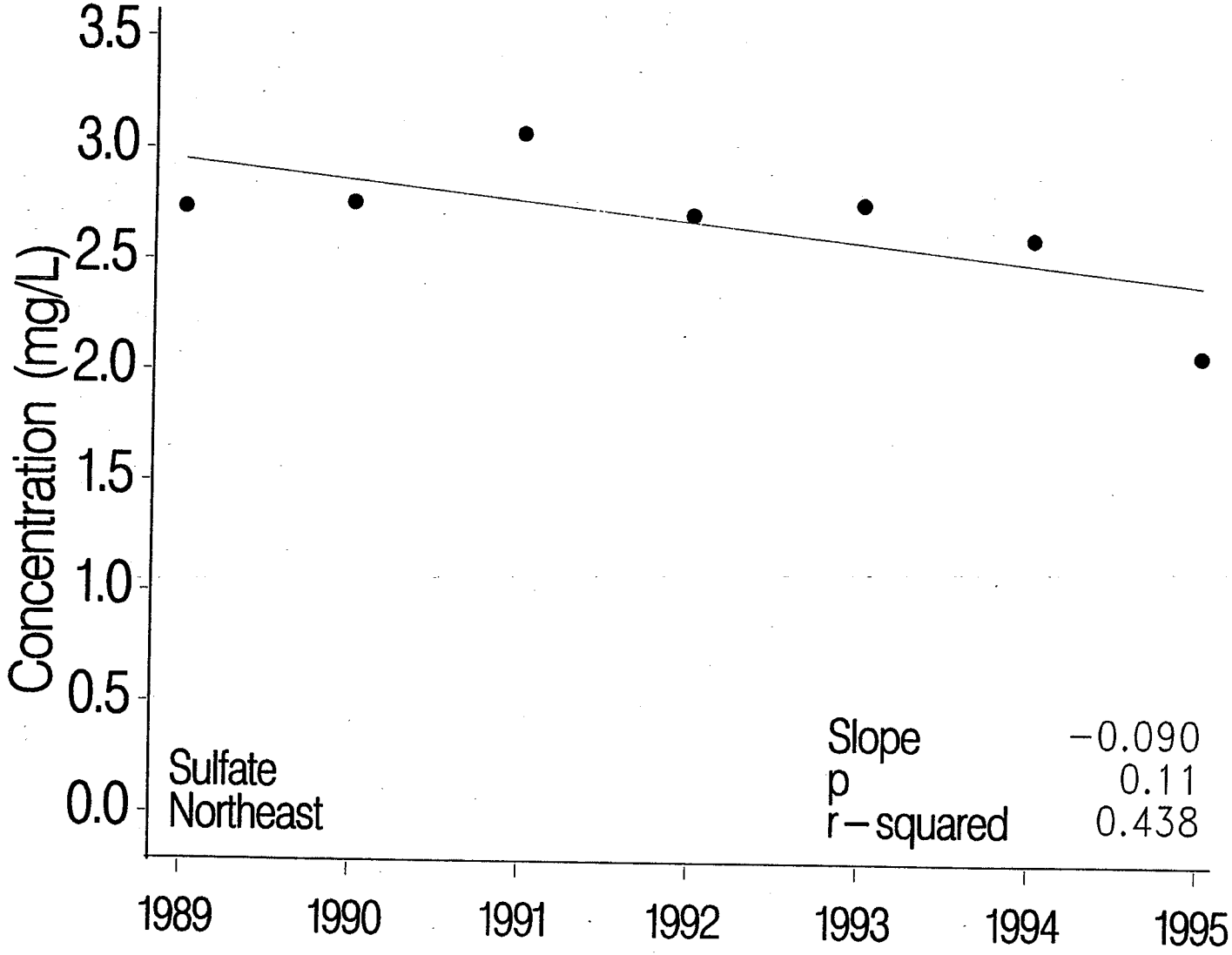


Figure 3-128. Linear regression analysis of SO_4^{2-} concentrations versus year for the northeast subregion (combined CDN/NADP data)

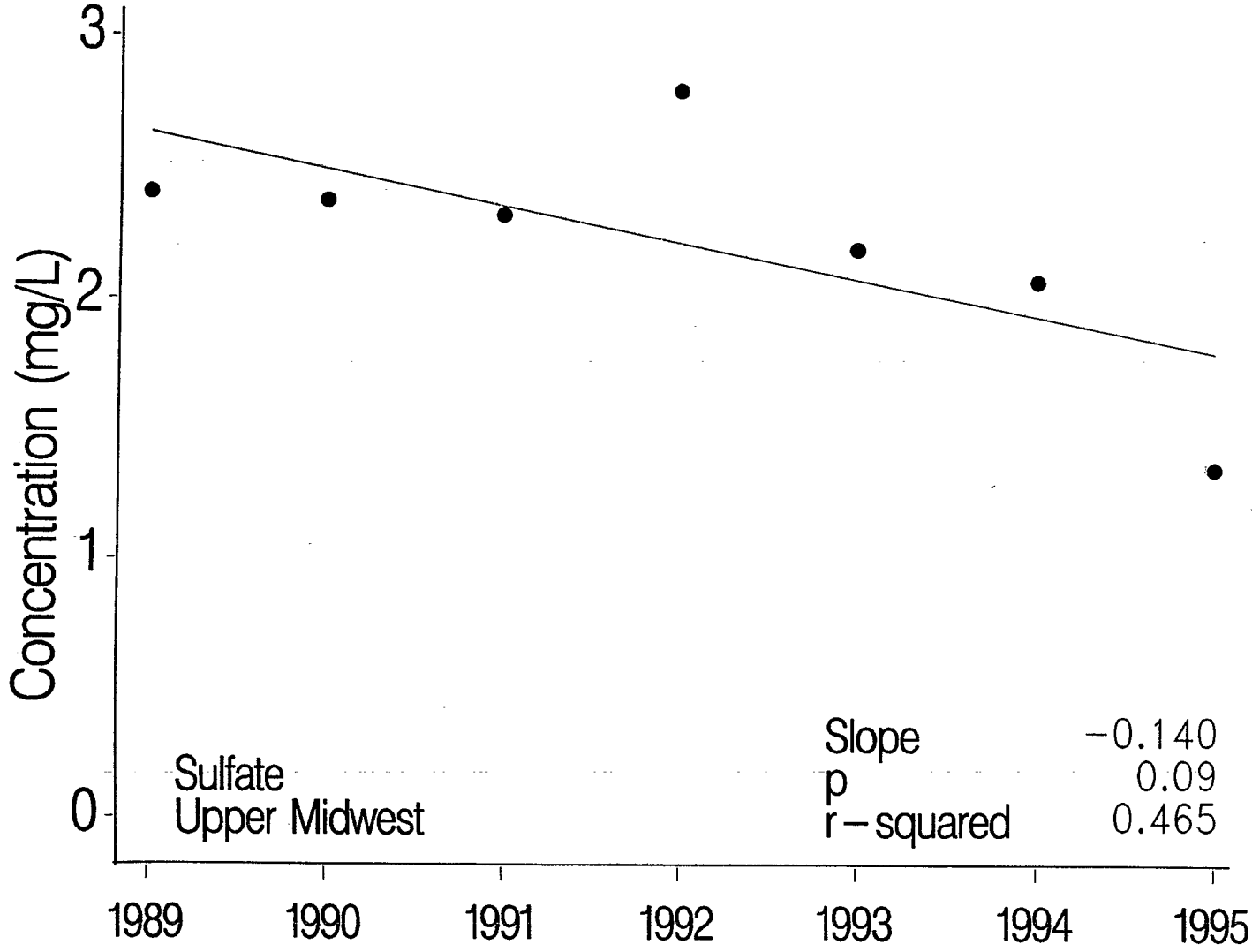


Figure 3-129. Linear regression analysis of SO_4^{2-} concentrations versus year for the upper midwest subregion (combined CDN/NADP data)

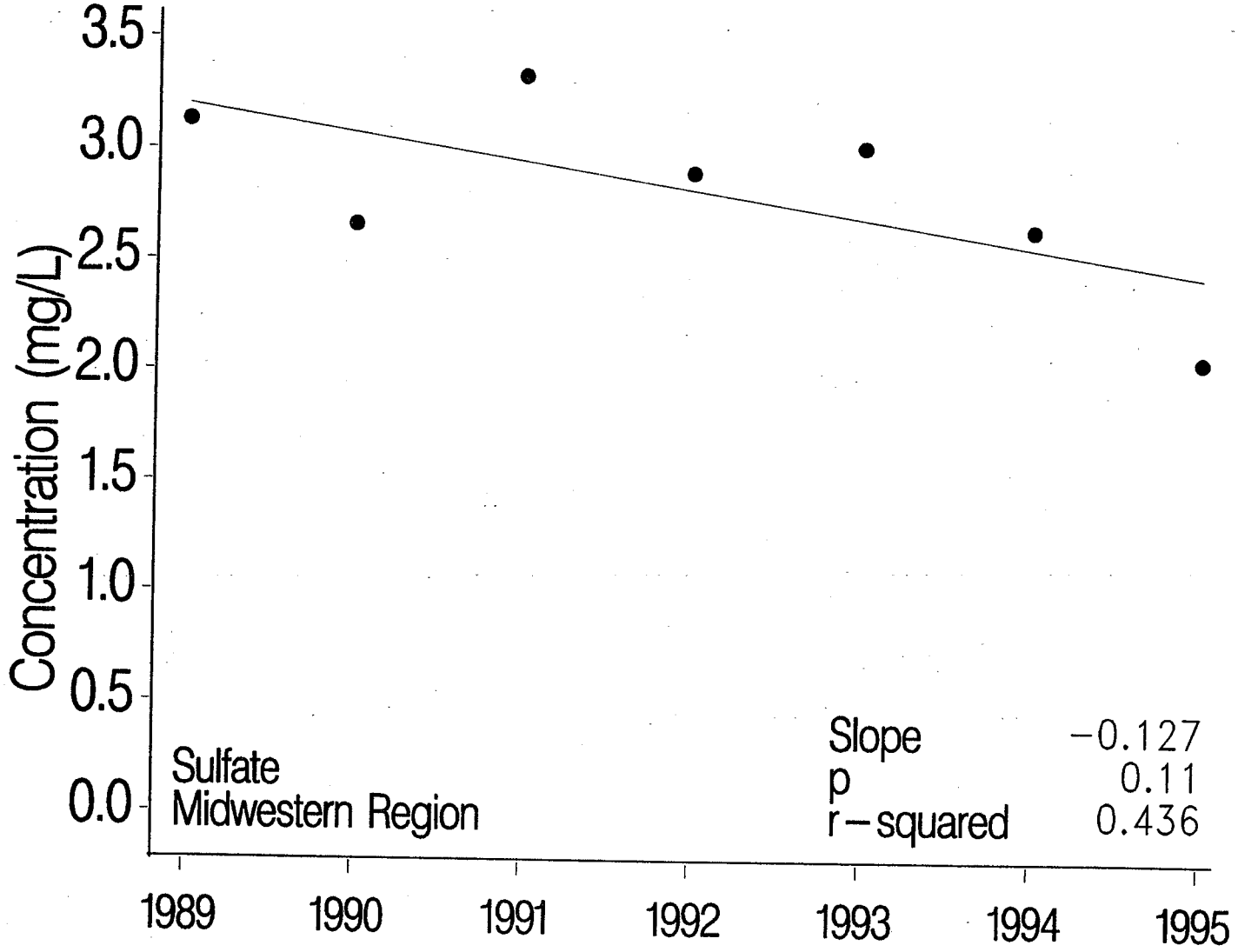


Figure 3-130. Linear regression analysis of SO_4^{2-} concentrations versus year for the midwest subregion (combined CDN/NADP data)

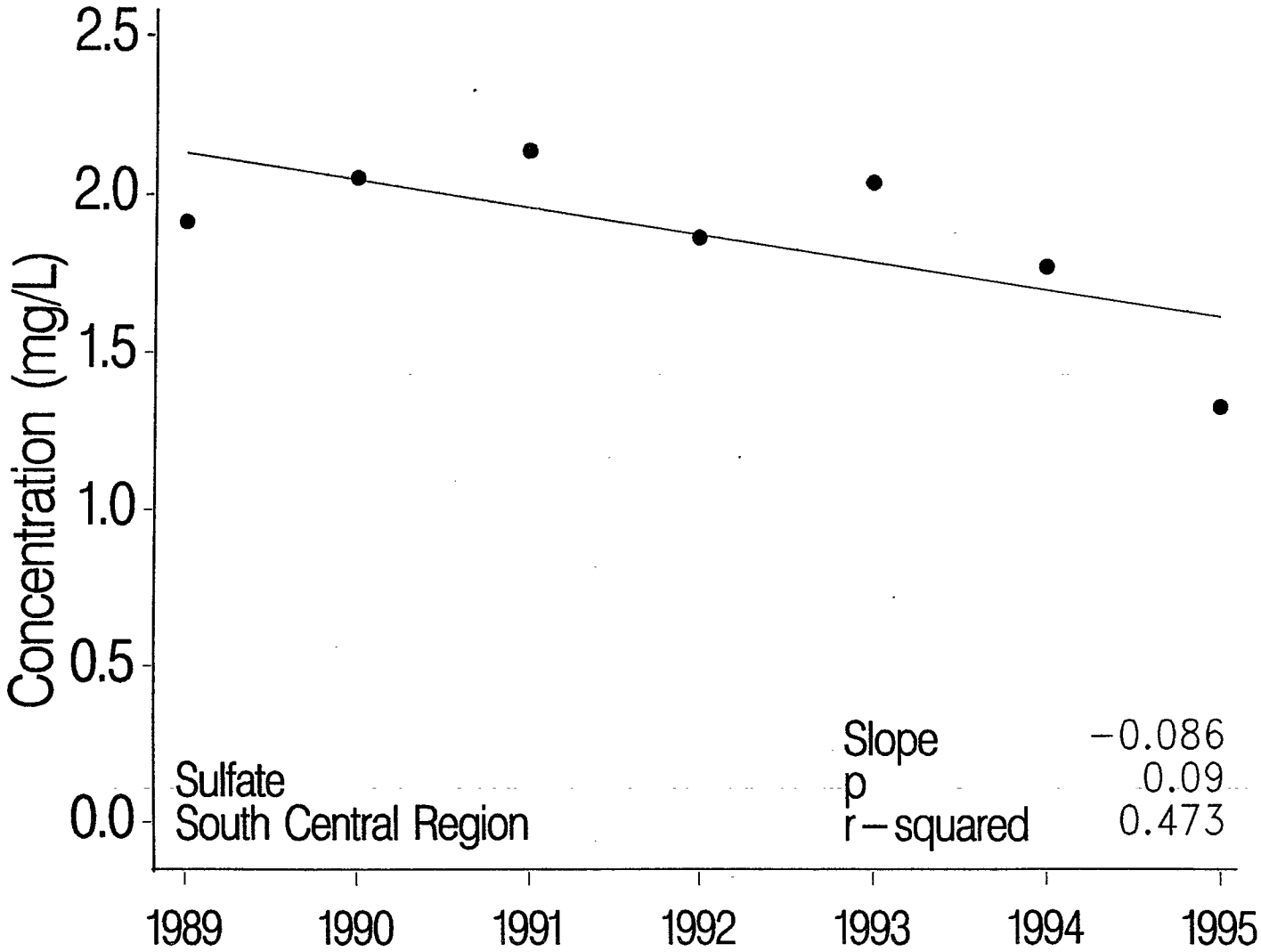


Figure 3-131. Linear regression analysis of SO_4^{2-} concentrations versus year for the south-central subregion (combined CDN/NADP data)

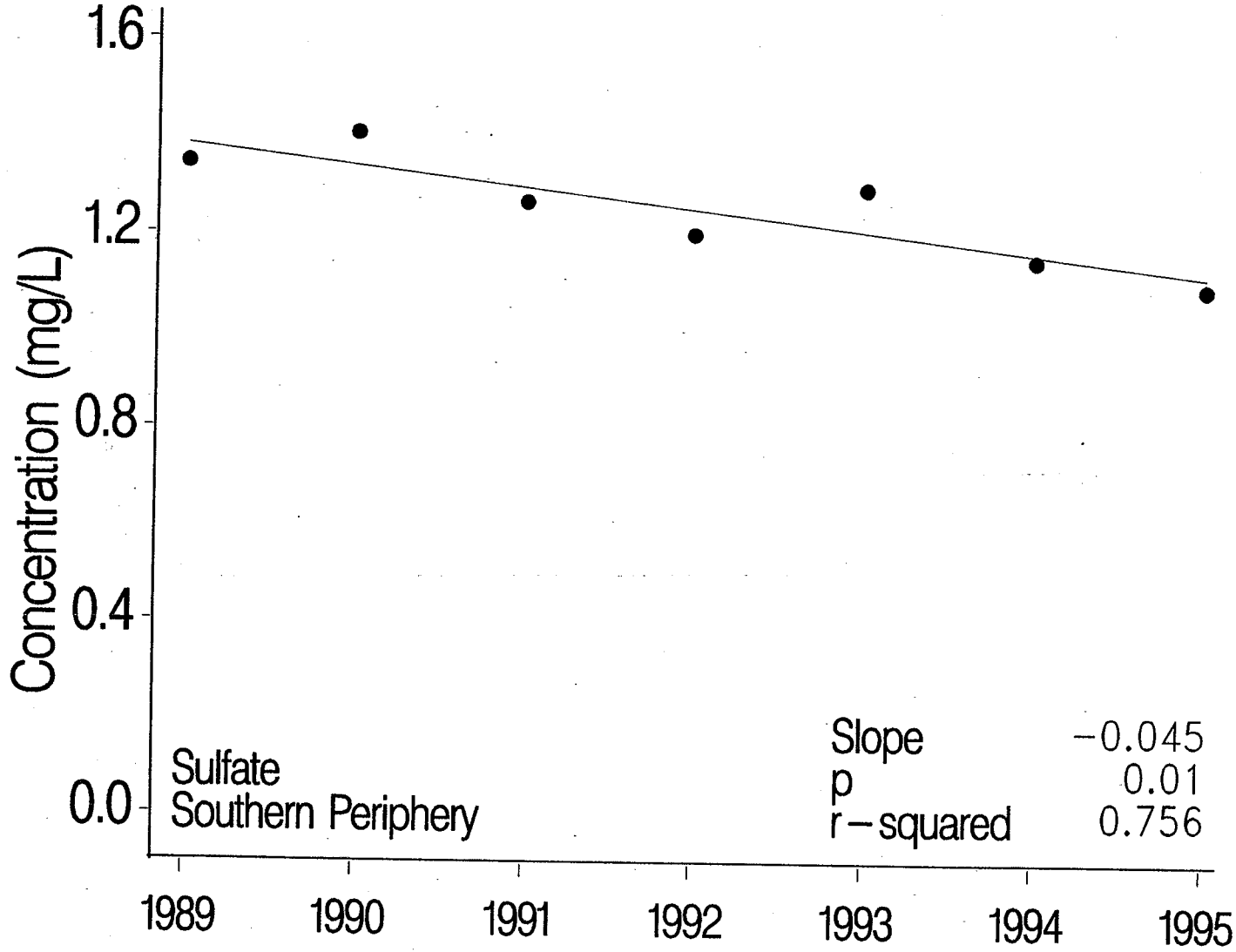


Figure 3-132. Linear regression analysis of SO_4^{2-} concentrations versus year for the southern periphery subregion (combined CDN/NADP data)

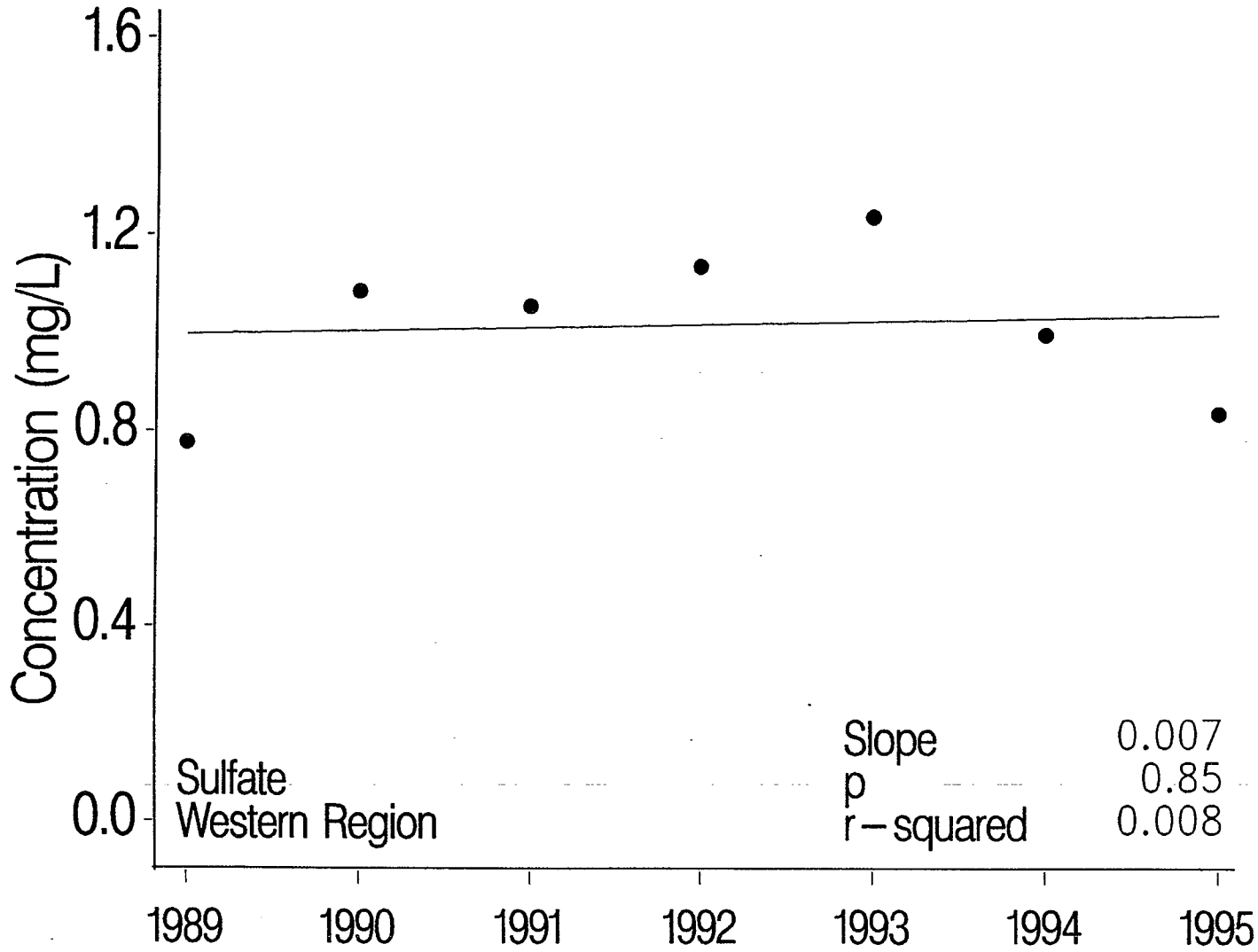


Figure 3-133. Linear regression analysis of SO_4^{2-} concentrations versus year for the western region (combined CDN/NADP data)

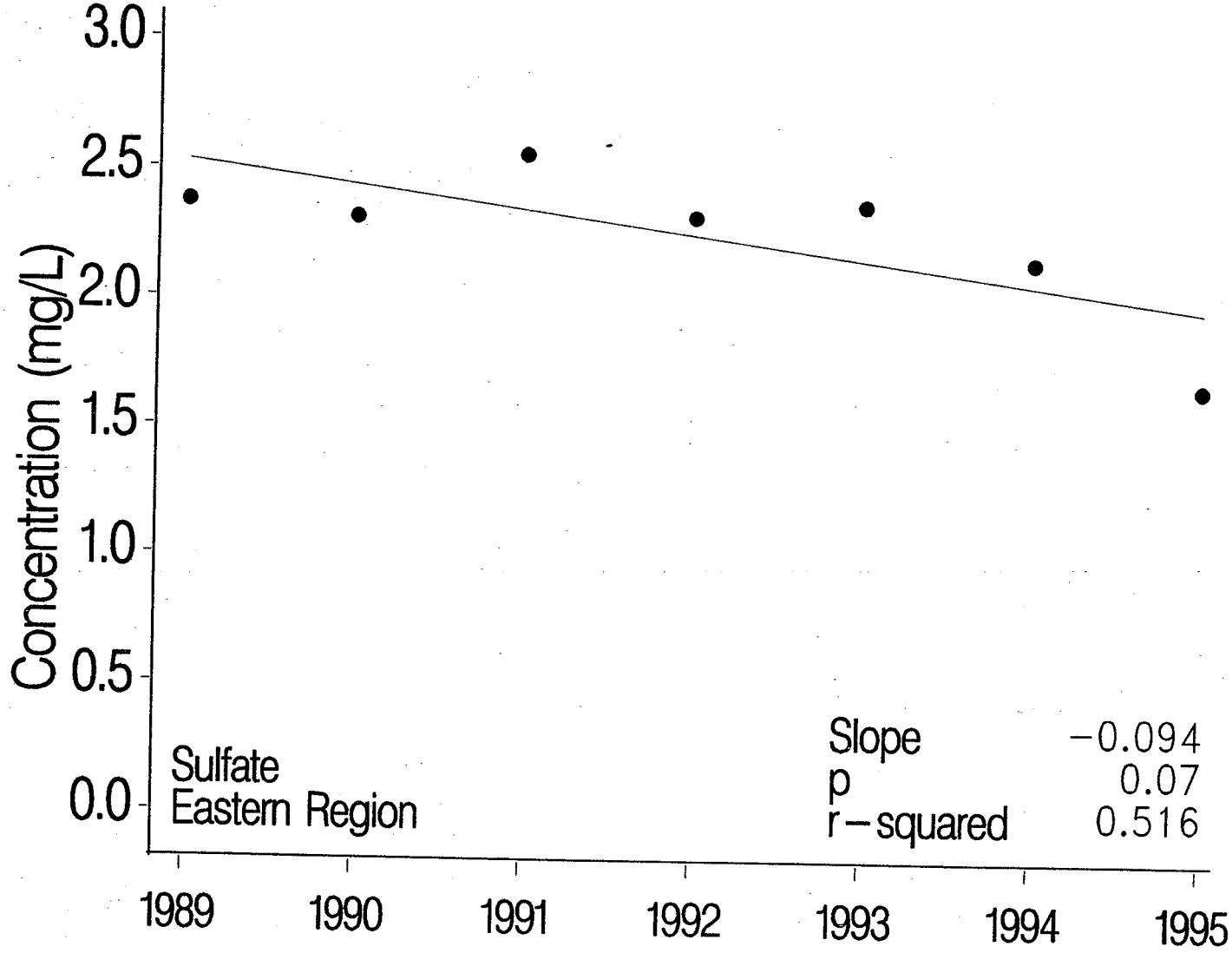


Figure 3-134. Linear regression analysis of SO_4^{2-} concentrations versus year for the eastern region (combined CDN/NADP data)

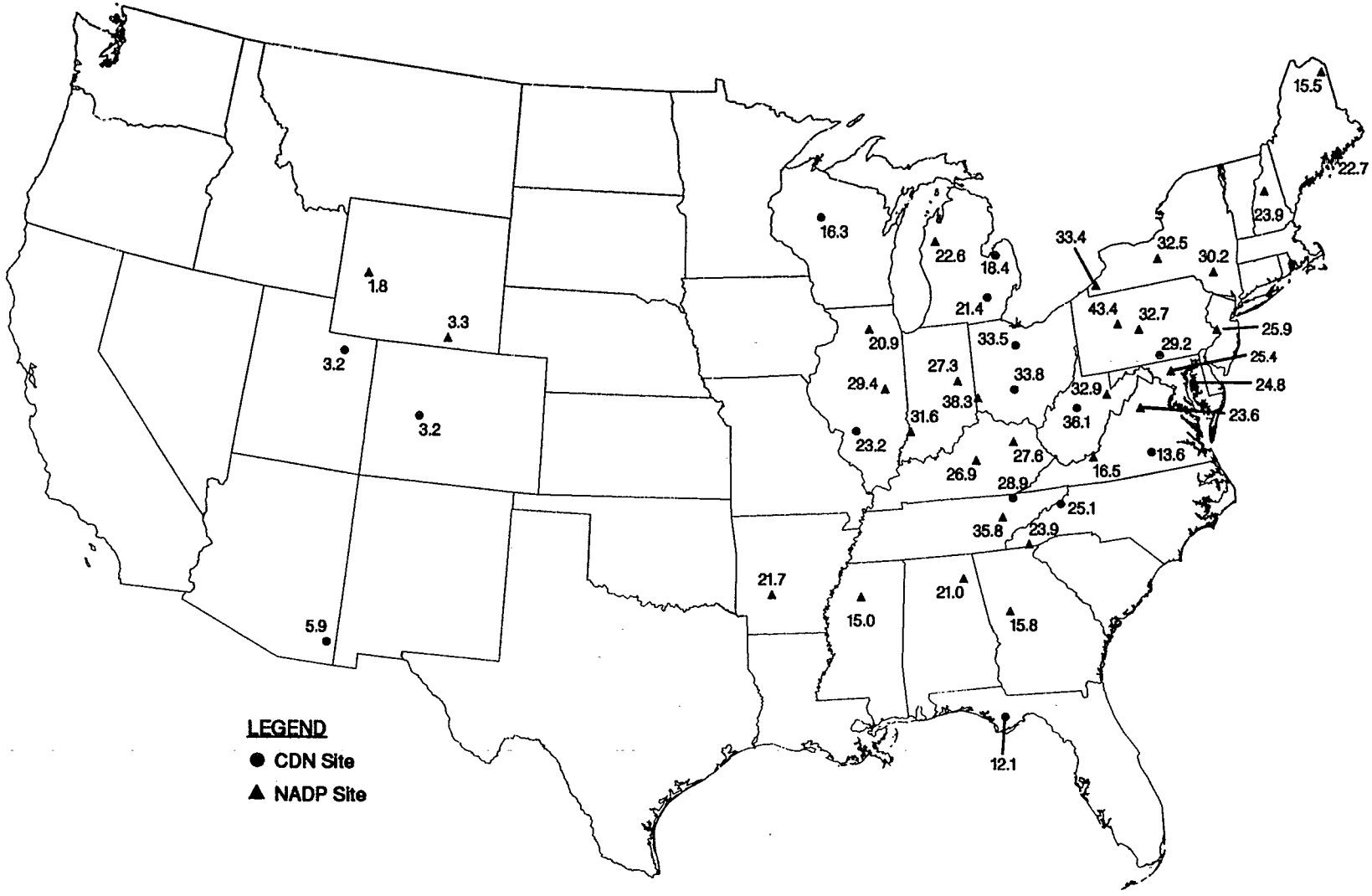


Figure 3-135. Combined CDN/NADP annual average deposition rates for SO_4^{2-} (kg/ha) for 1990

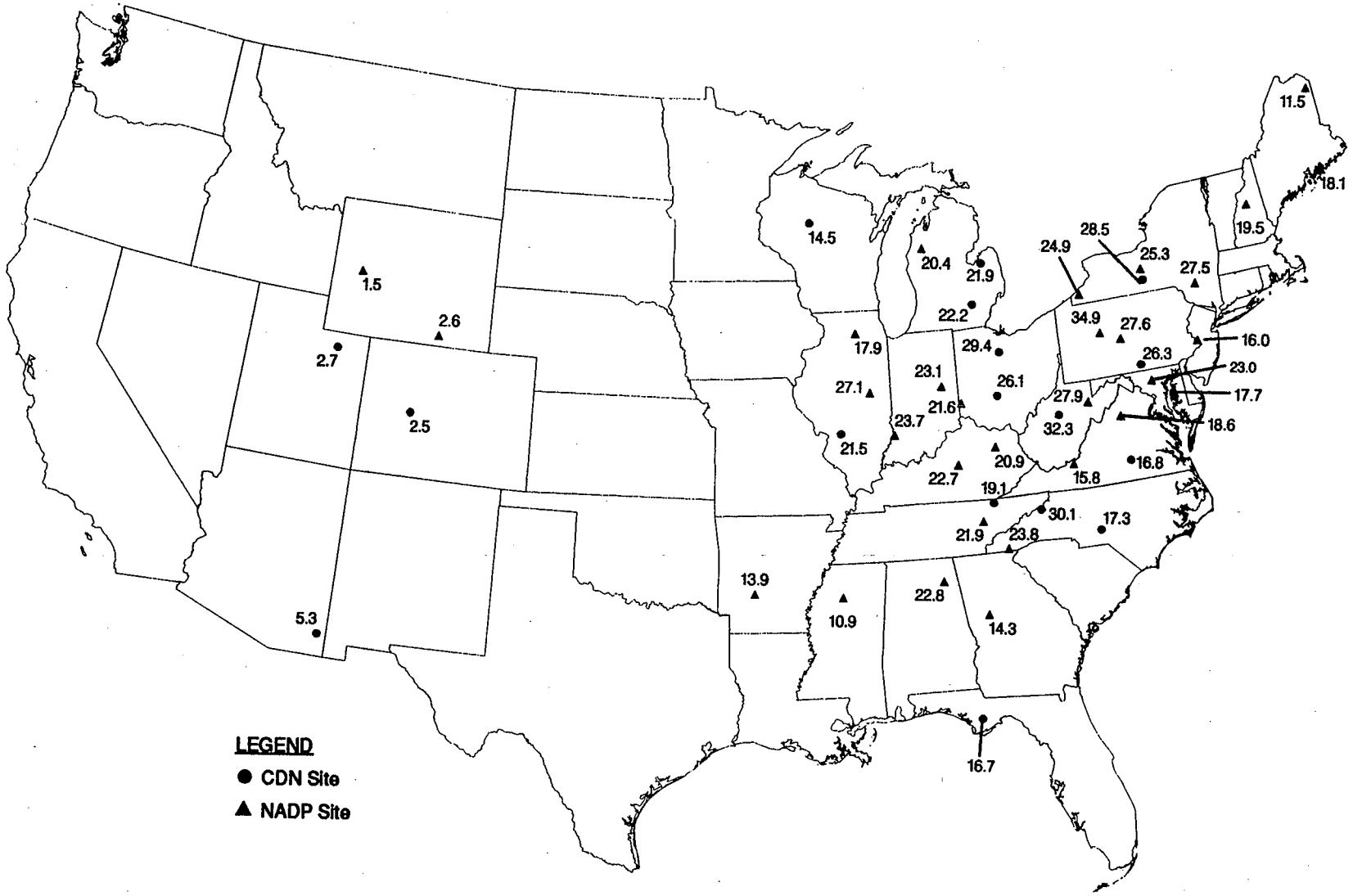


Figure 3-136. Combined CDN/NADP annual average deposition rates for SO_4^{2-} (kg/ha) for 1992

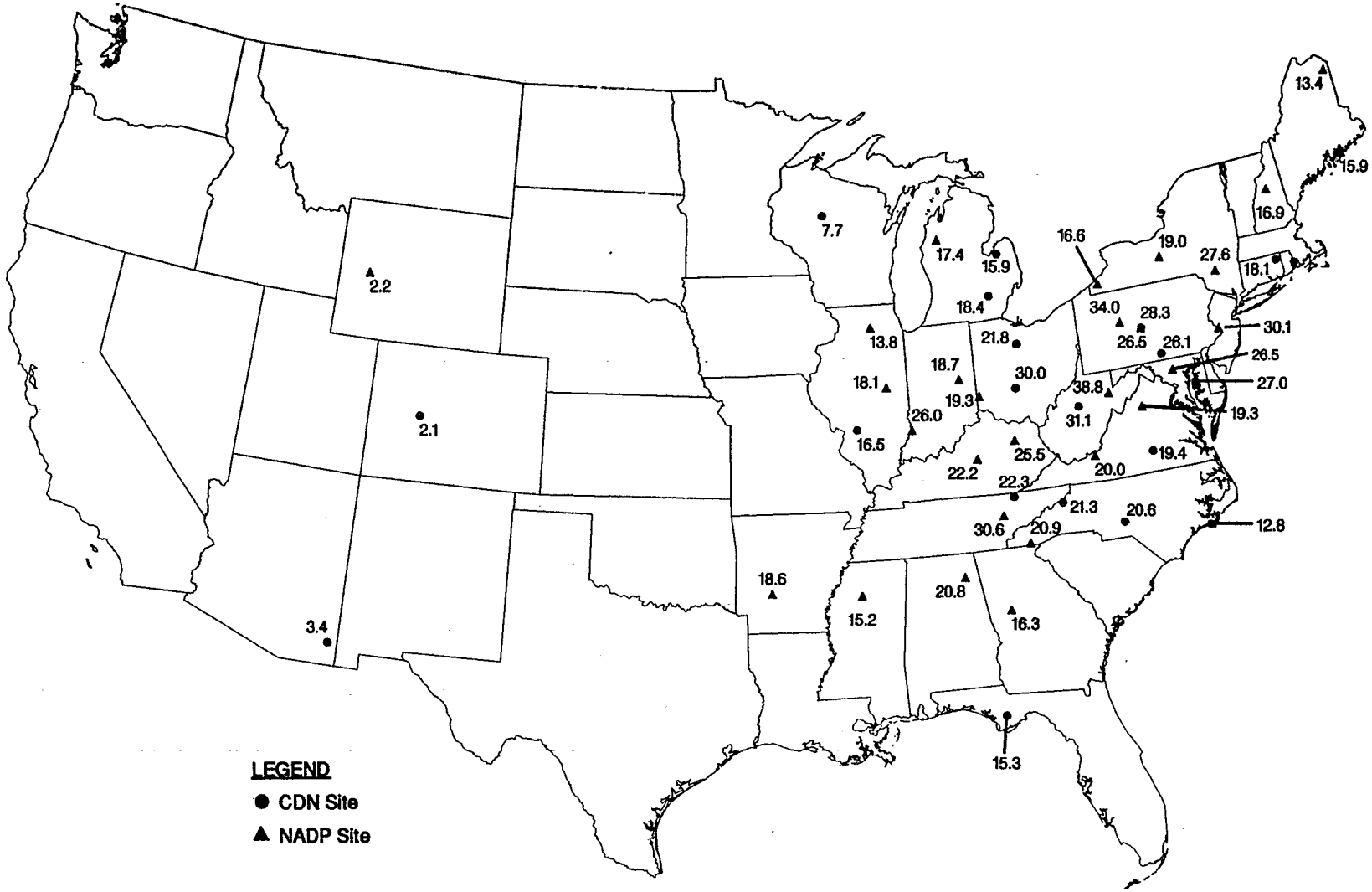


Figure 3-137. Combined CDN/NADP annual average deposition rates for SO_4^{2-} (kg/ha) for 1994

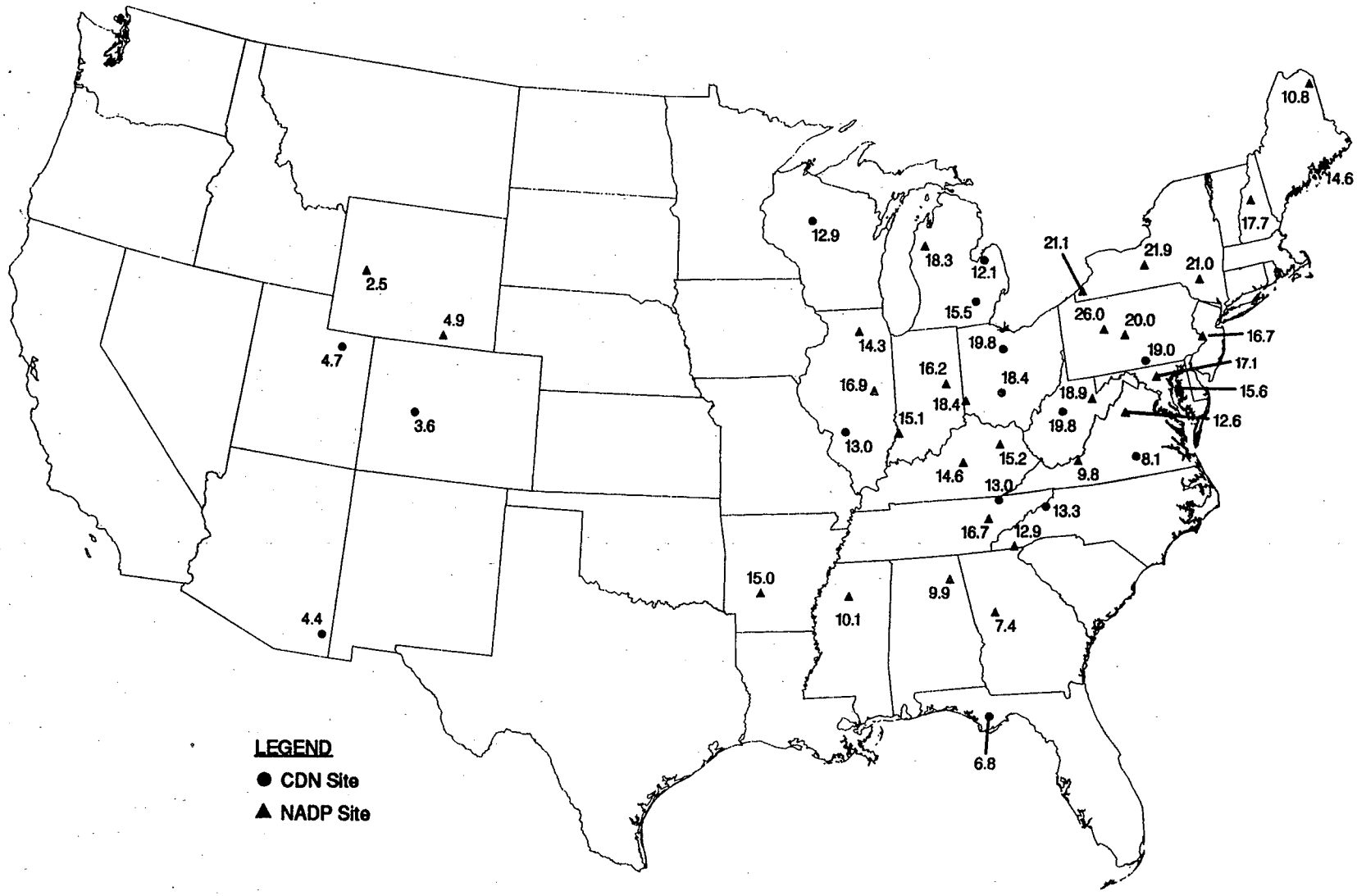


Figure 3-138. Combined CDN/NADP annual average deposition rates for NO_3^- (kg/ha) for 1990

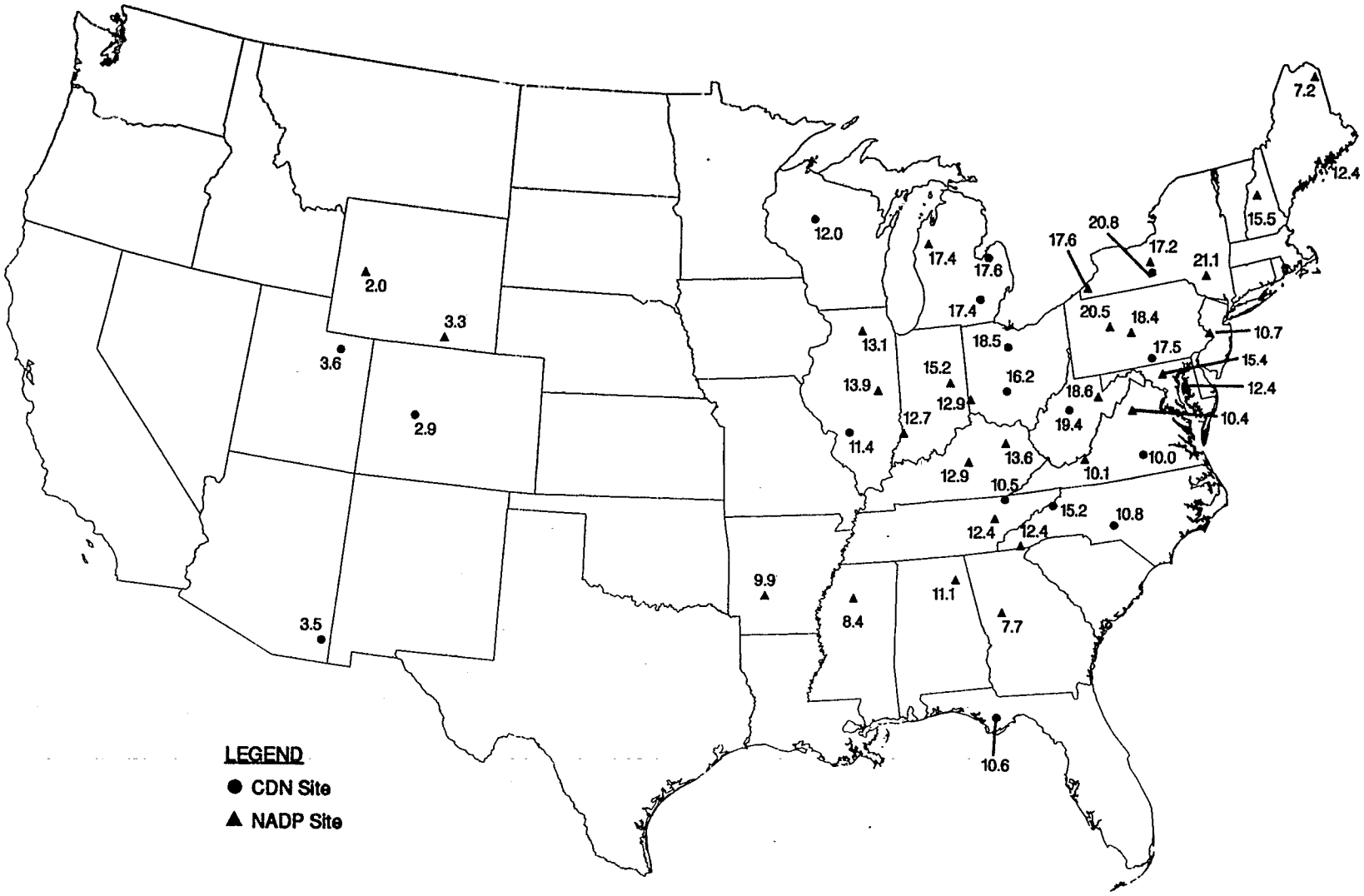


Figure 3-139. Combined CDN/NADP annual average deposition rates for NO_3^- (kg/ha) for 1992

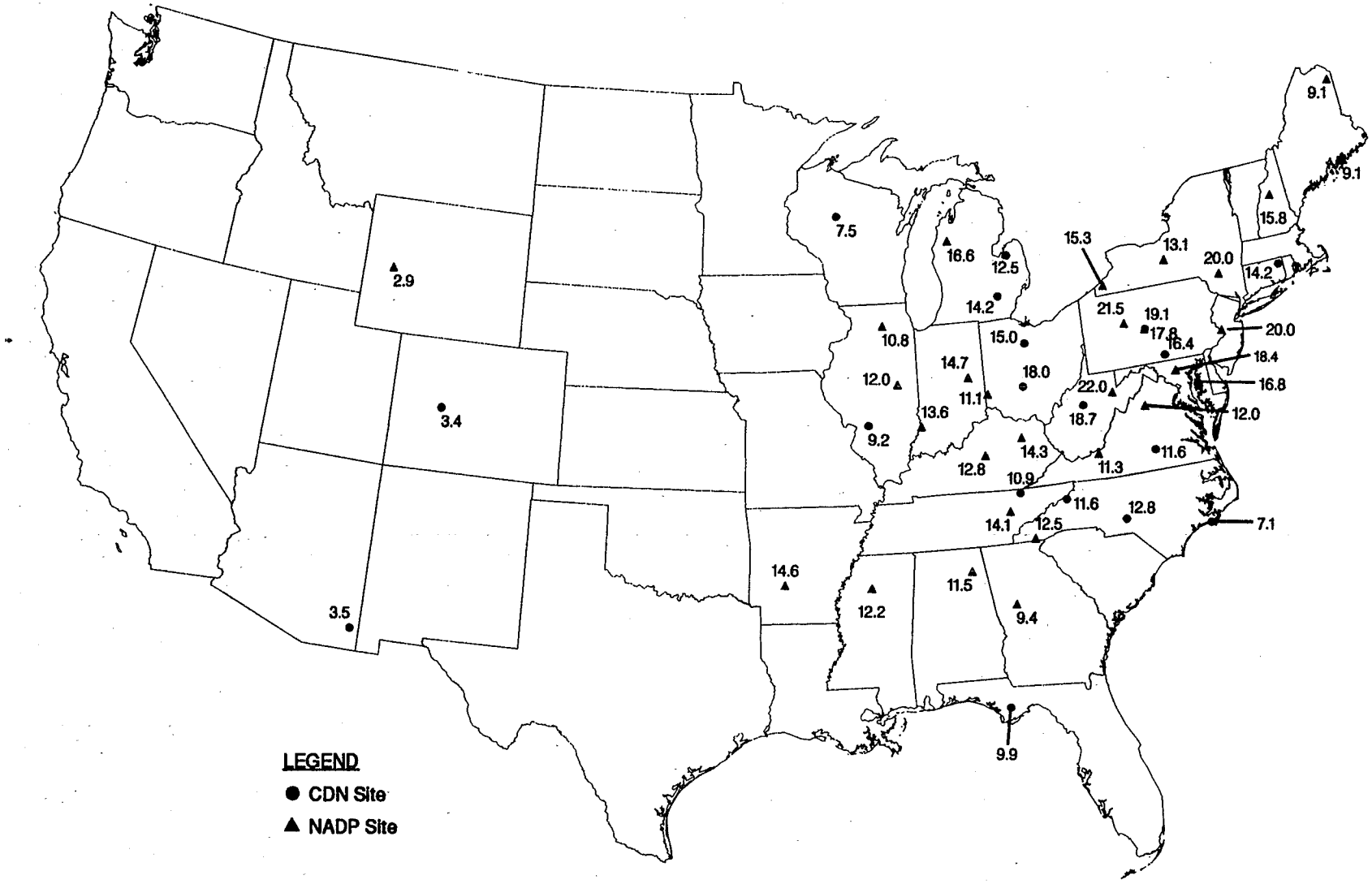


Figure 3-140. Combined CDN/NADP annual average deposition rates for NO_3^- (kg/ha) for 1994

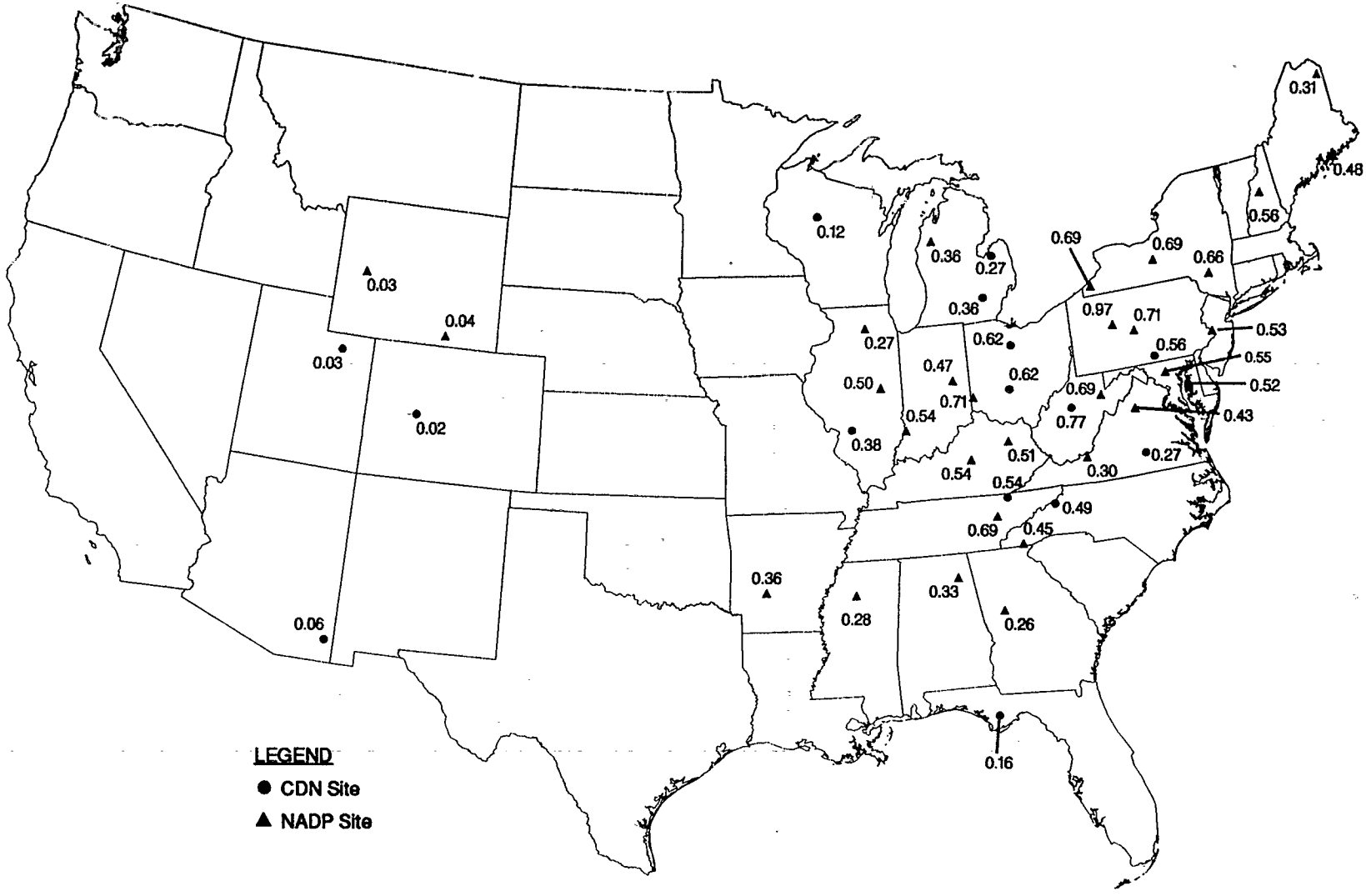


Figure 3-141. Combined CDN/NADP annual average deposition rates for H^+ (kg/ha) for 1990

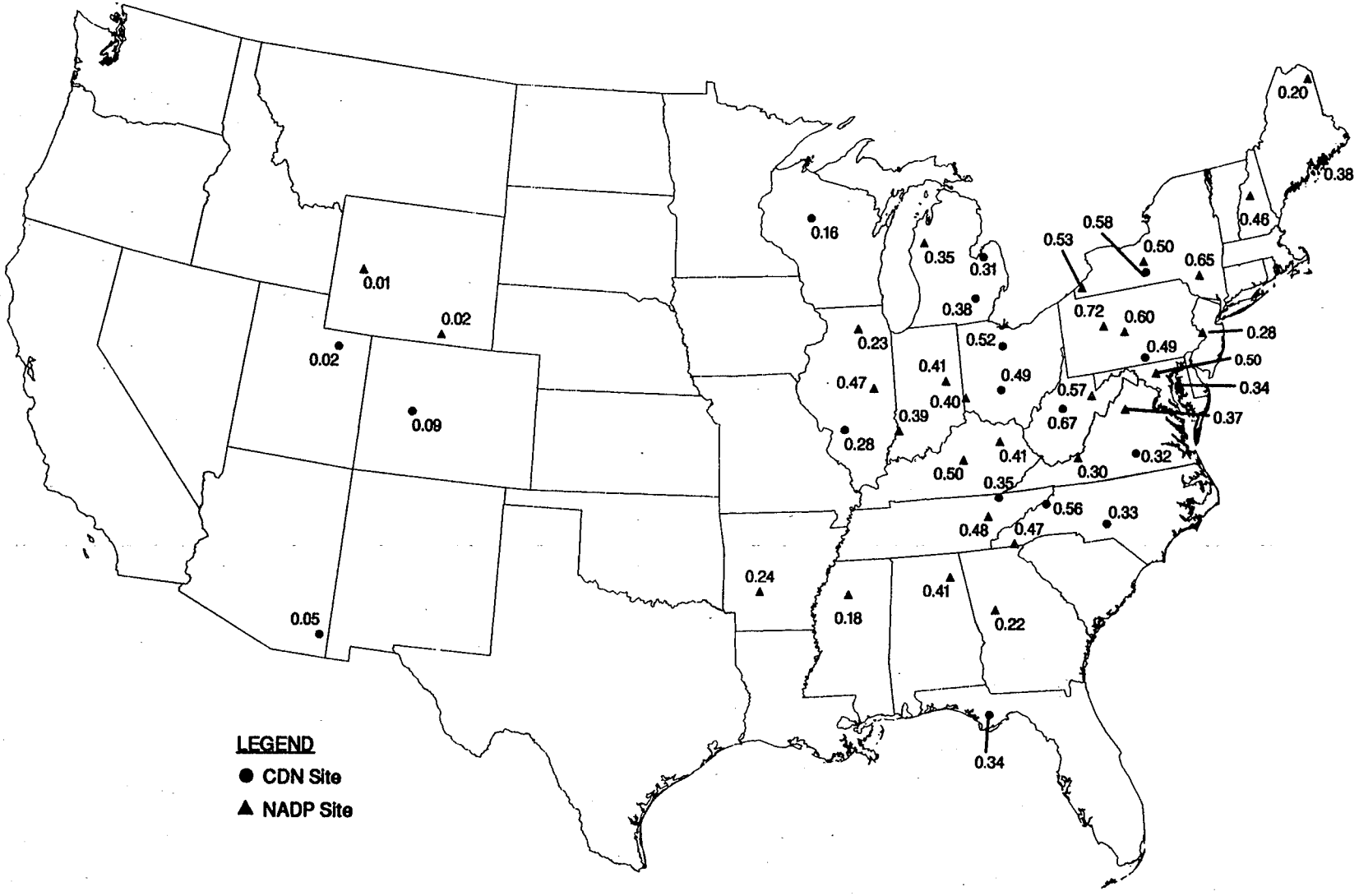


Figure 3-142. Combined CDN/NADP annual average deposition rates for H^+ (kg/ha) for 1992

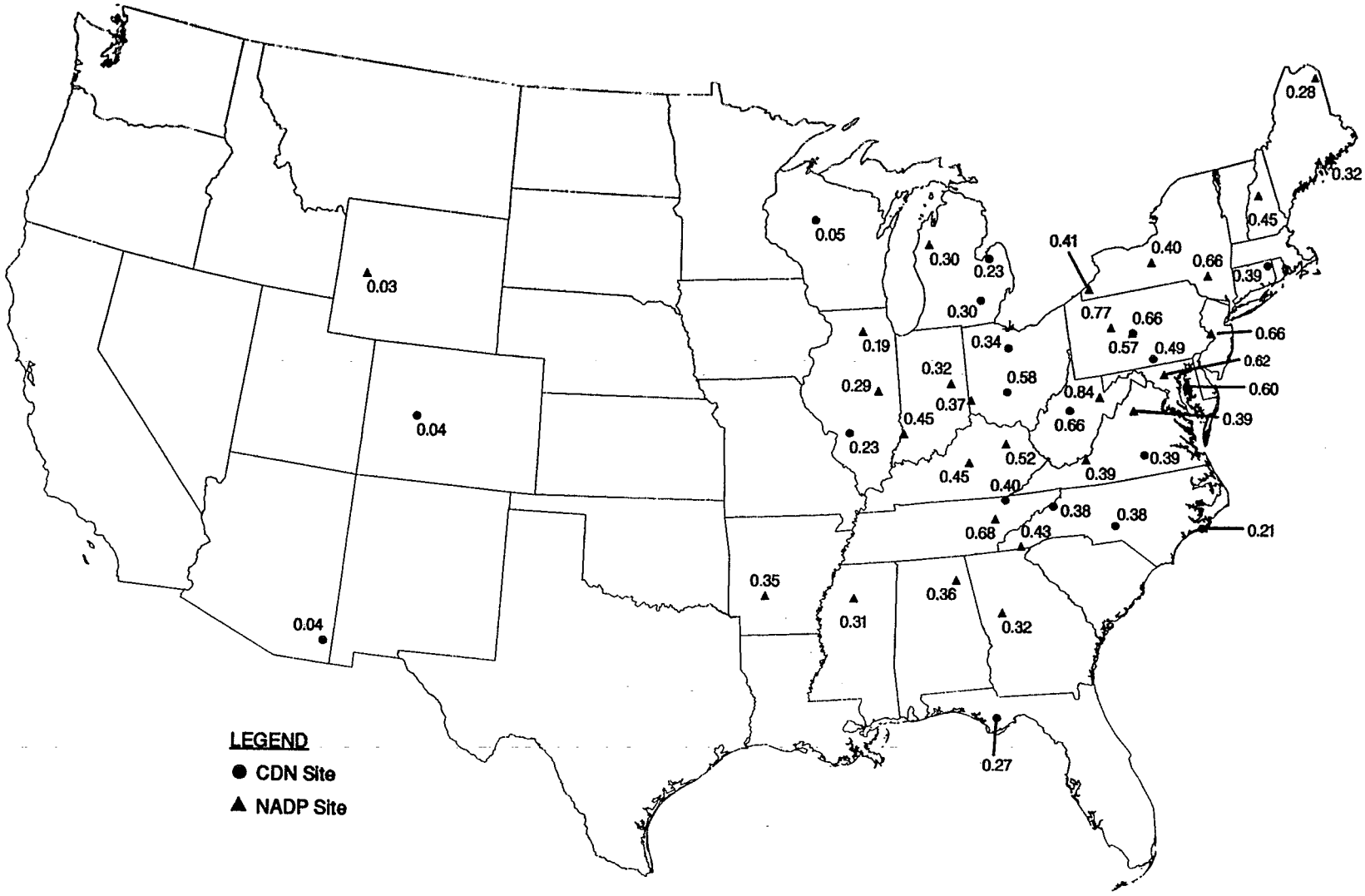


Figure 3-143. Combined CDN/NADP annual average deposition rates for H^+ (kg/ha) for 1994

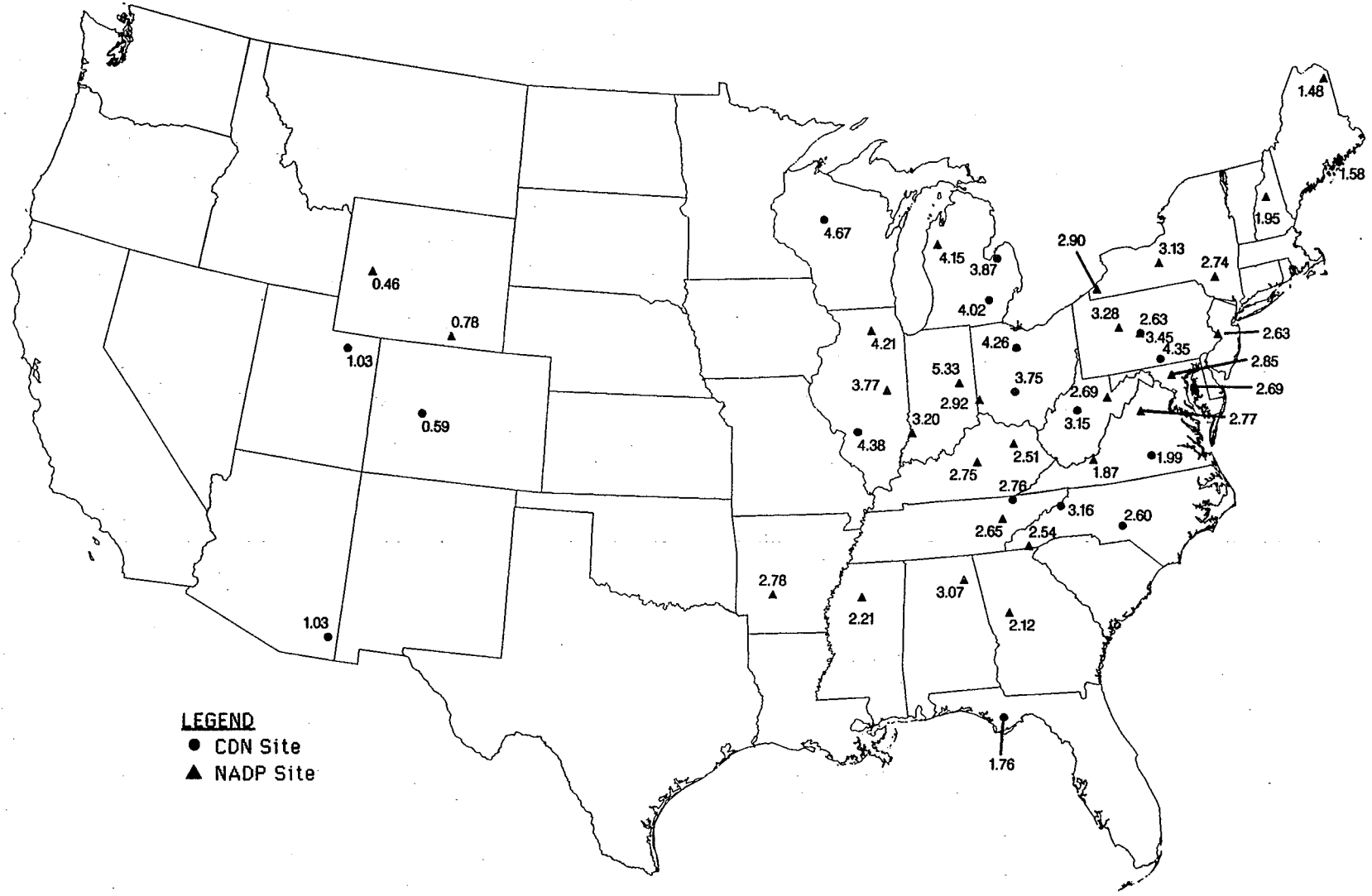


Figure 3-144. Combined CDN/NADP five-year average NH_4^+ depositions (kg/ha) from 1990 to 1994

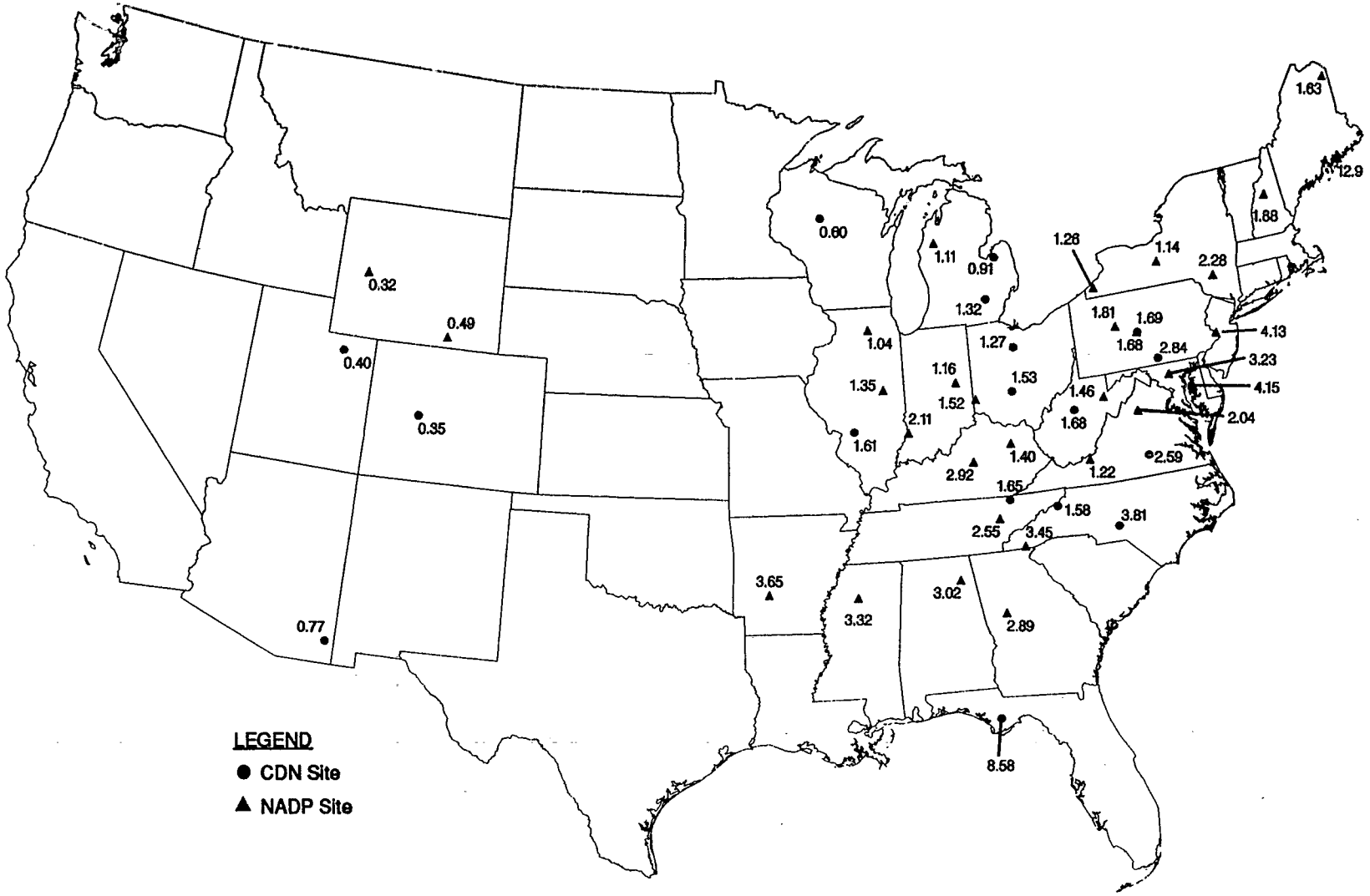


Figure 3-145. Combined CDN/NADP five-year average deposition rates for Cl^- (kg/ha) from 1990 to 1994

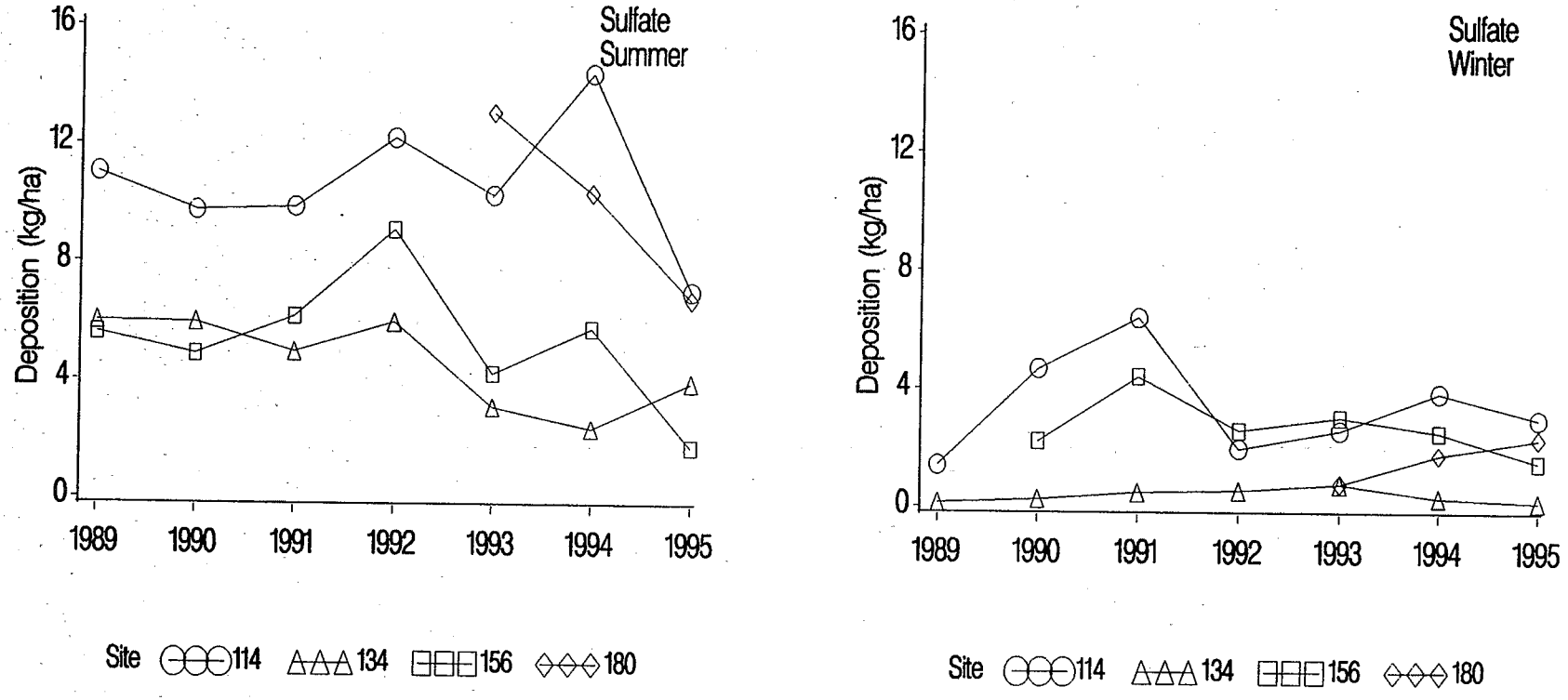


Figure 3-146. Seasonal (summer vs. winter) variability of SO_4^{2-} (kg/ha) for four eastern sites (114, 134, 156, and 180)

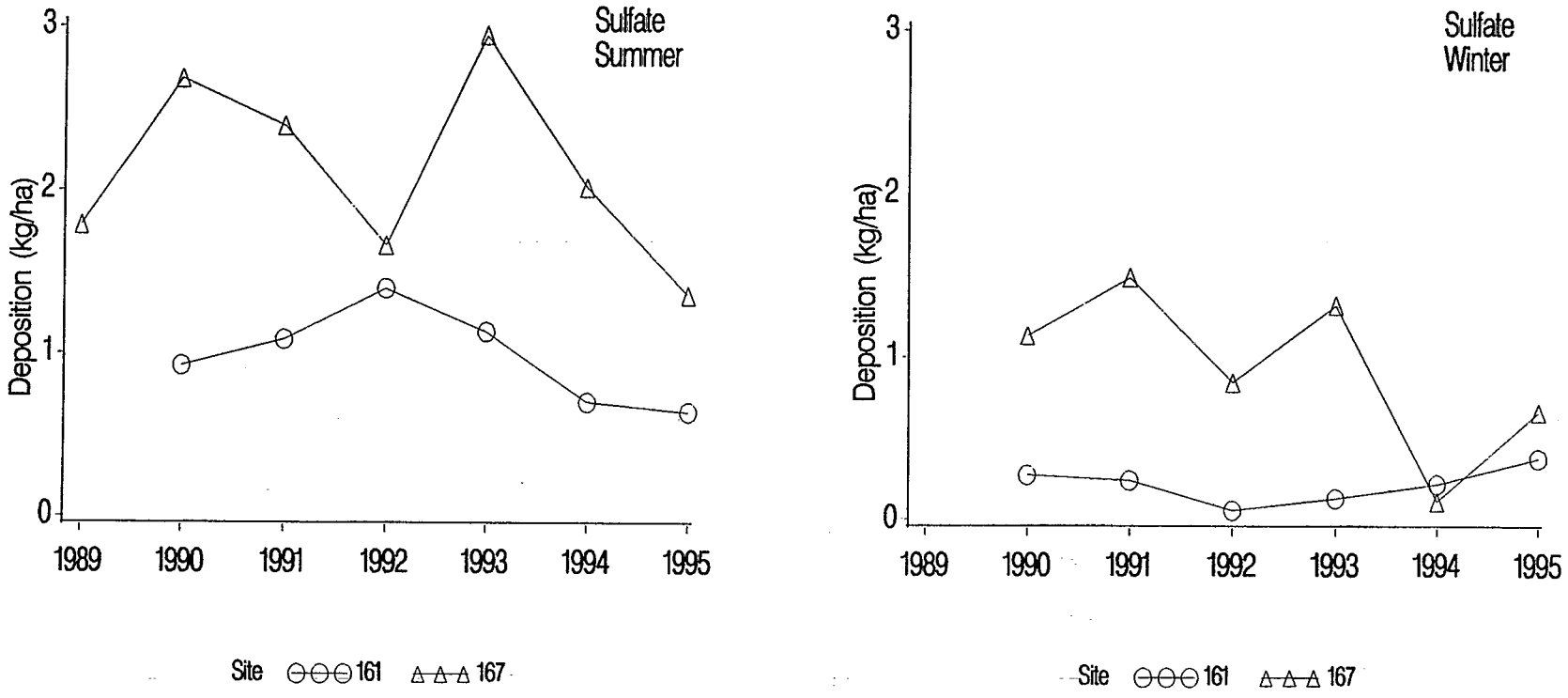


Figure 3-147. Seasonal (summer vs. winter) variability of SO_4^{2-} (kg/ha) for two western sites (161 and 167)

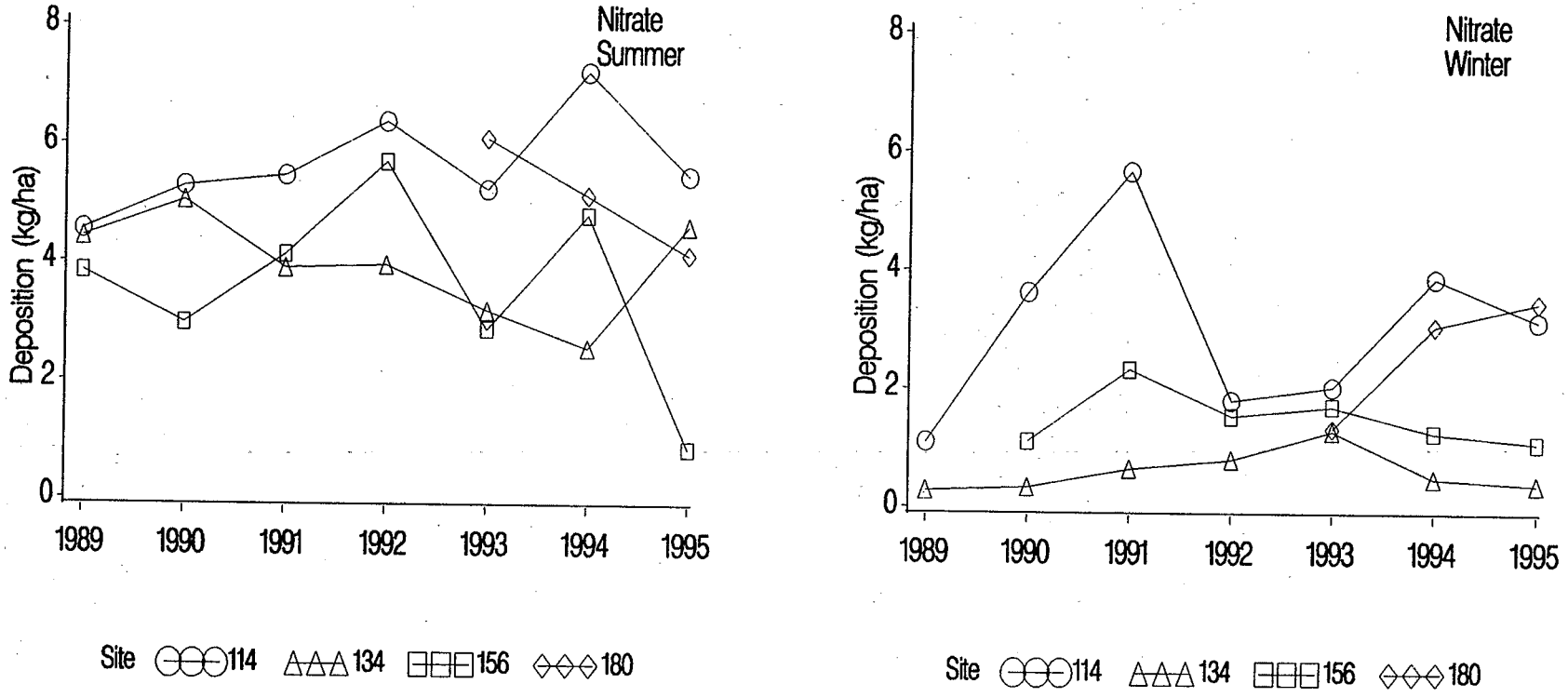


Figure 3-148. Seasonal (summer vs. winter) variability of NO_3^- (kg/ha) for four eastern sites (114, 134, 156, and 180)

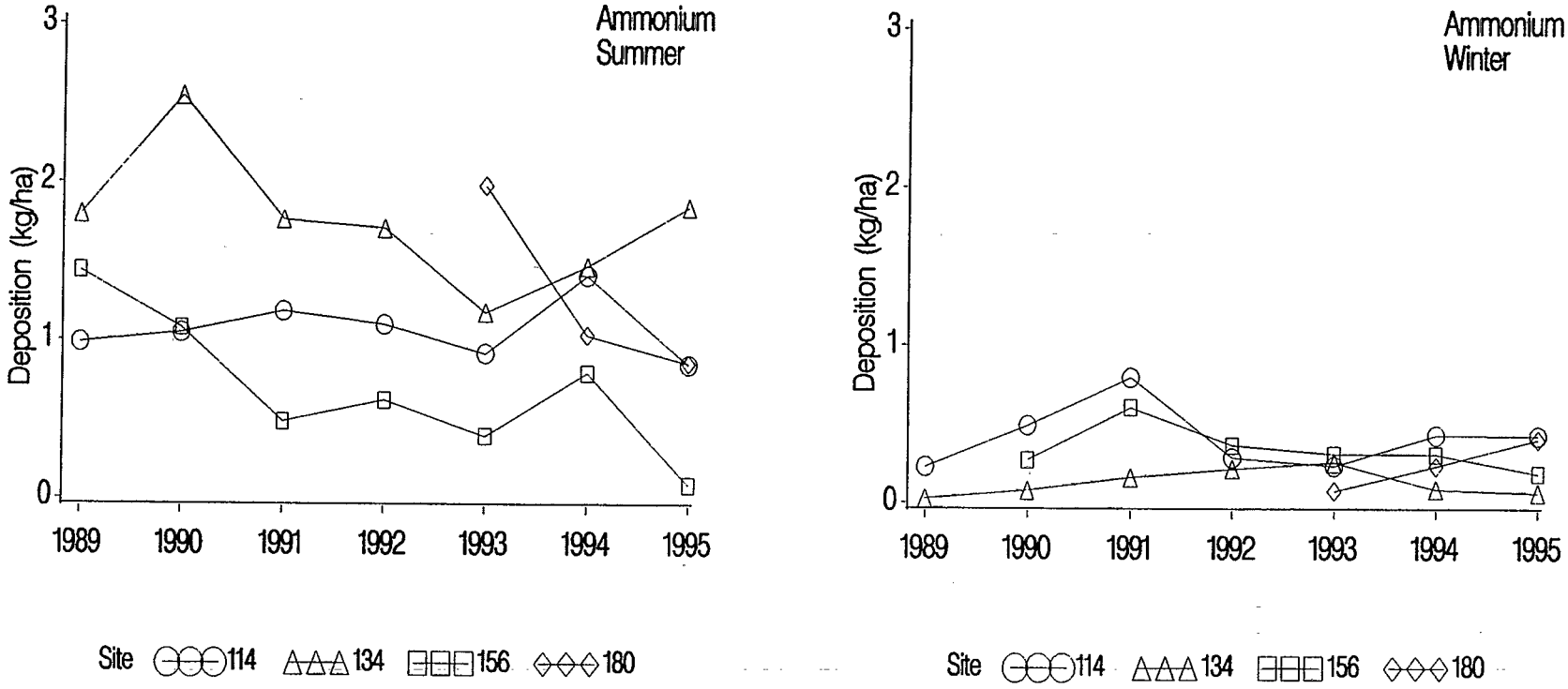


Figure 3-149. Seasonal (summer vs. winter) variability of NH_4^+ (kg/ha) for four eastern sites (114, 134, 156, and 180)

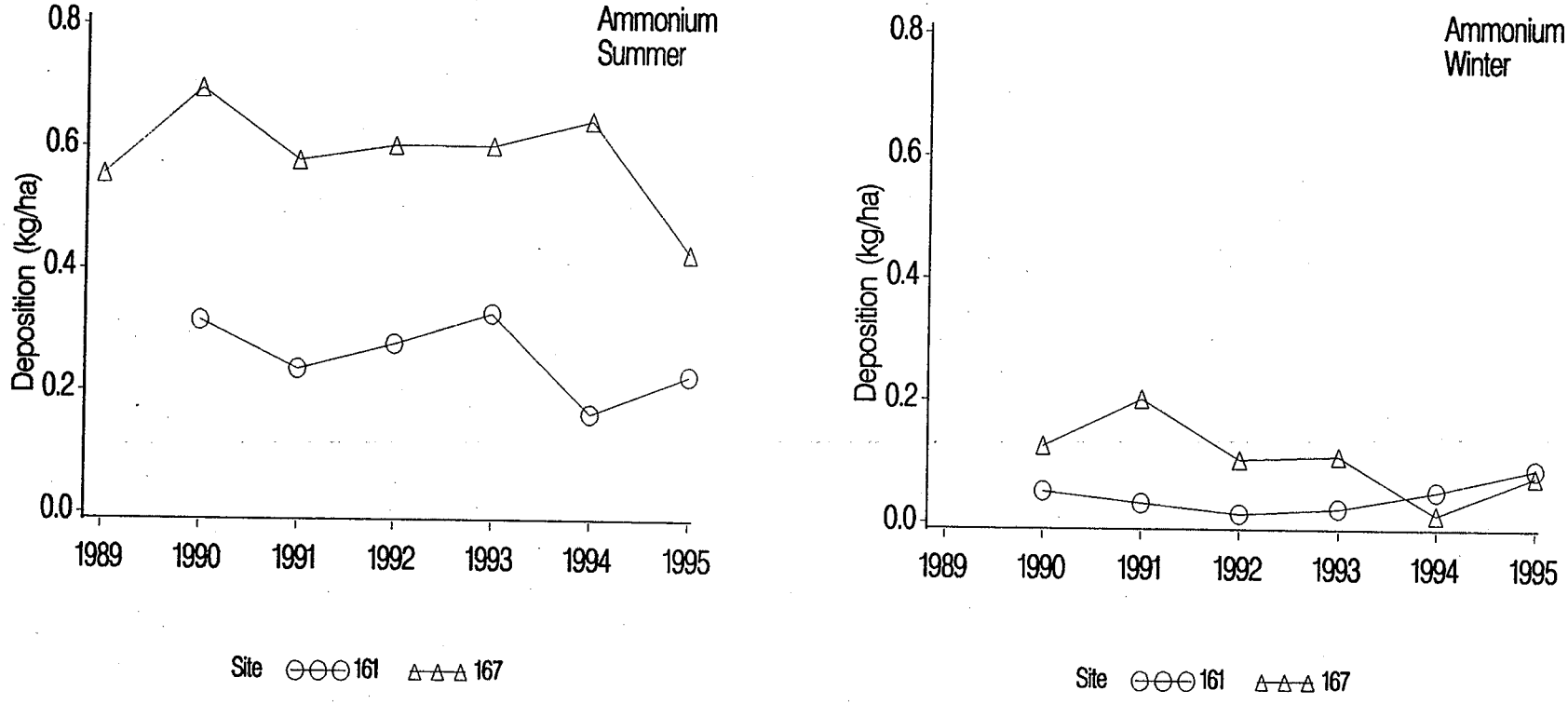


Figure 3-150. Seasonal (summer vs. winter) variability of NH_4^+ (kg/ha) for two western sites (161 and 167)

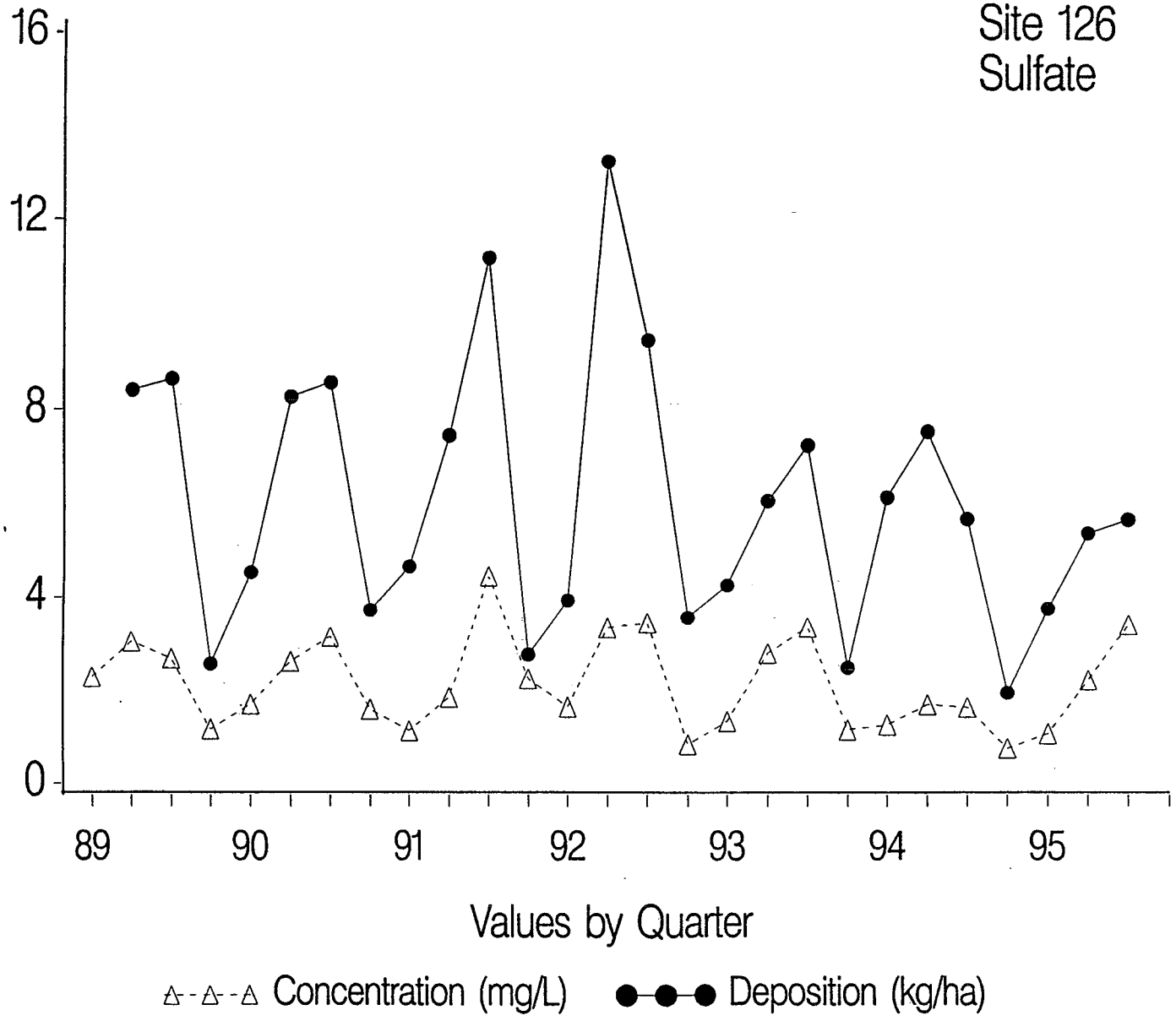


Figure 3-151. Quarterly average SO_4^{2-} concentrations and depositions for Site 126

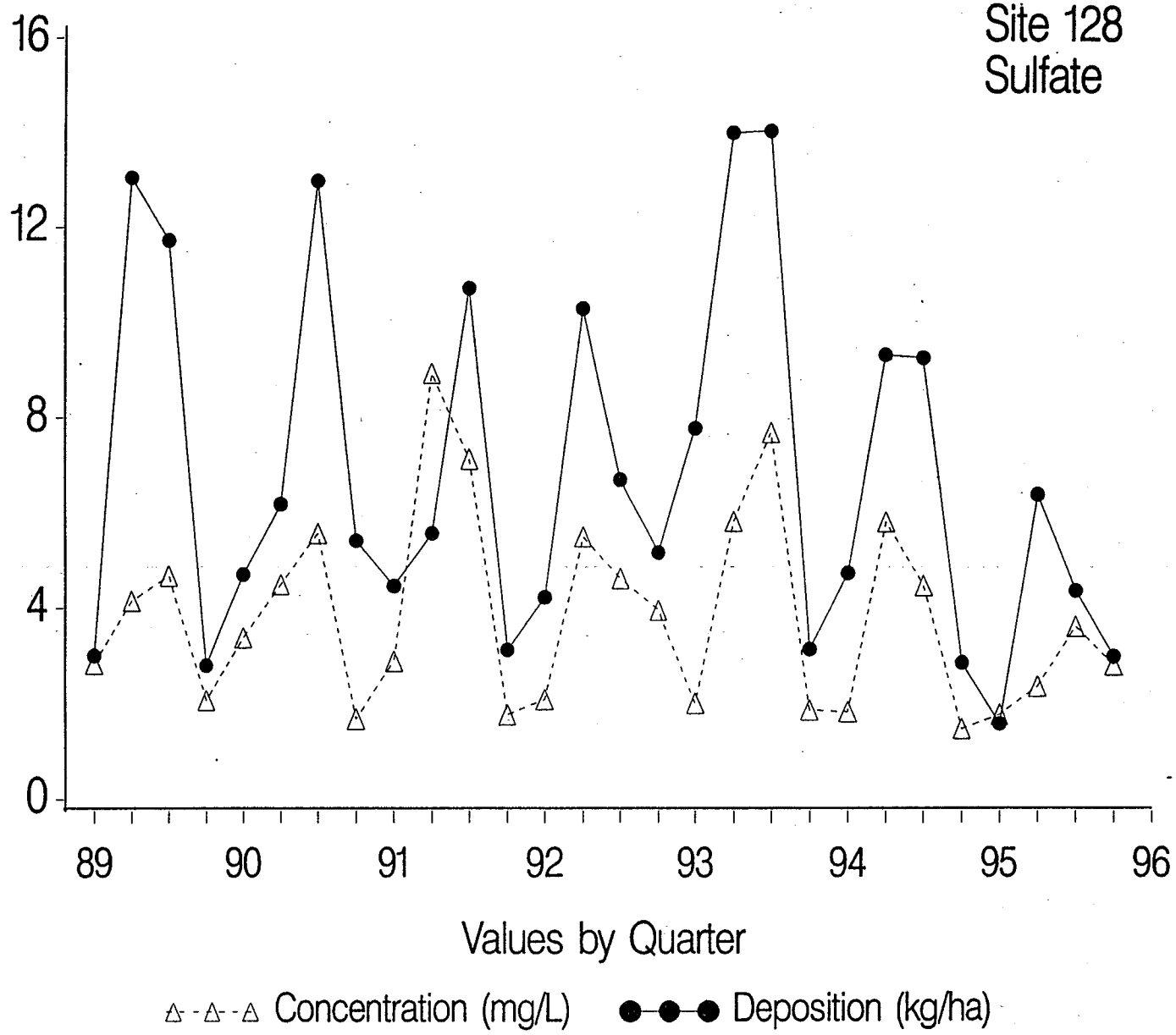


Figure 3-152. Quarterly average SO_4^{2-} concentrations and depositions for Site 128

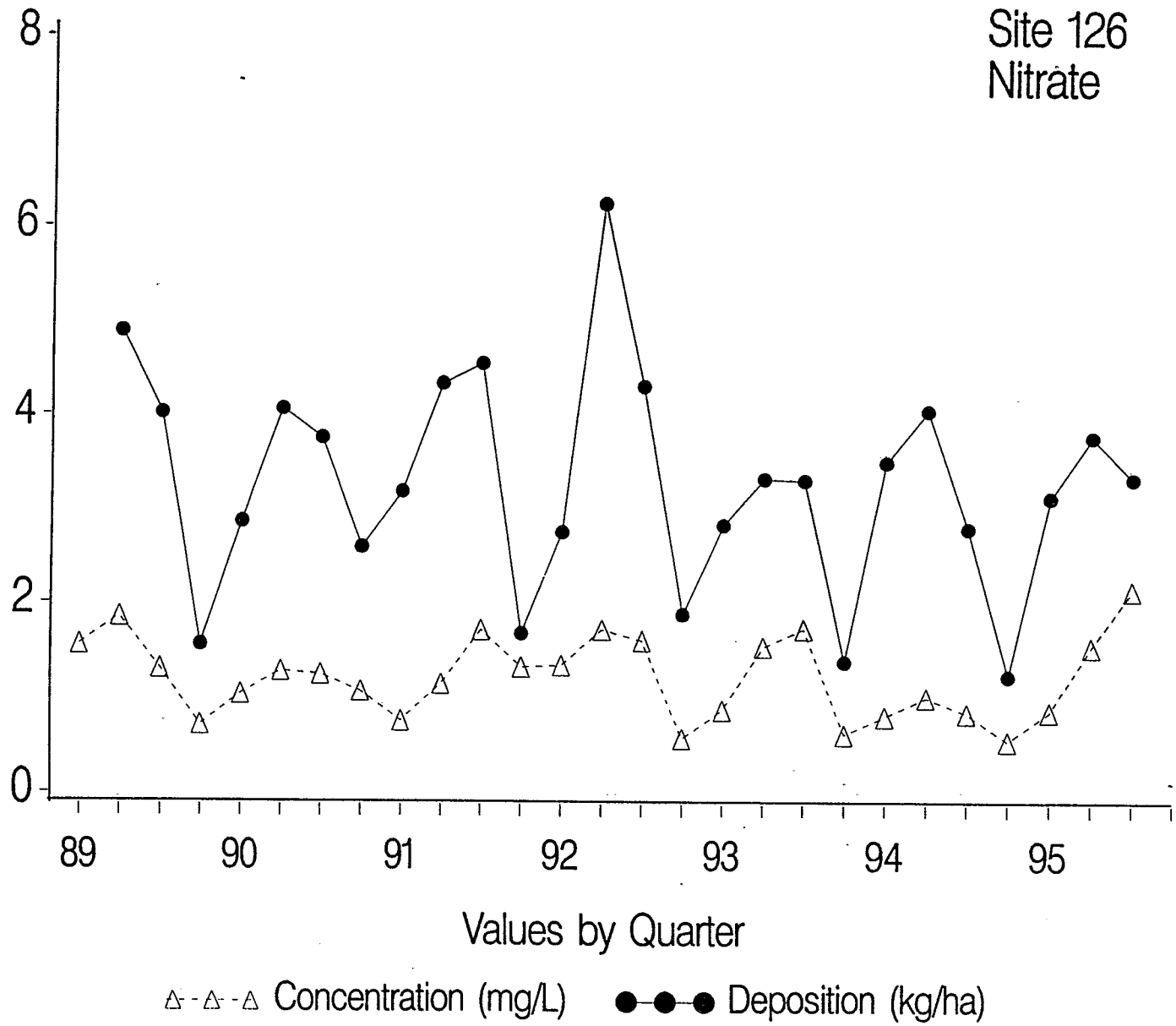


Figure 3-153. Quarterly average NO_3^- concentrations and depositions for Site 126

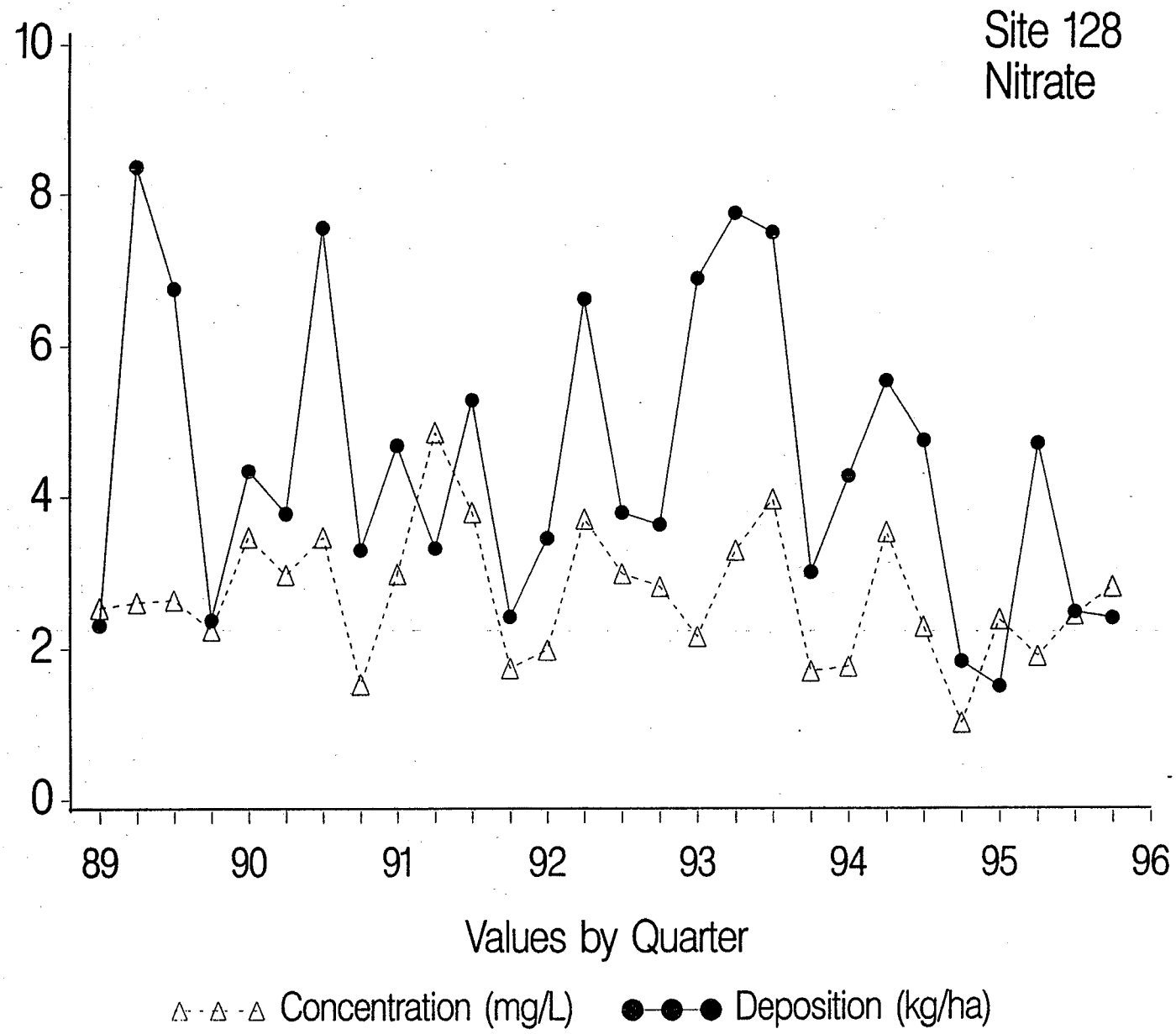


Figure 3-154. Quarterly average NO_3^- concentrations and depositions for Site 128

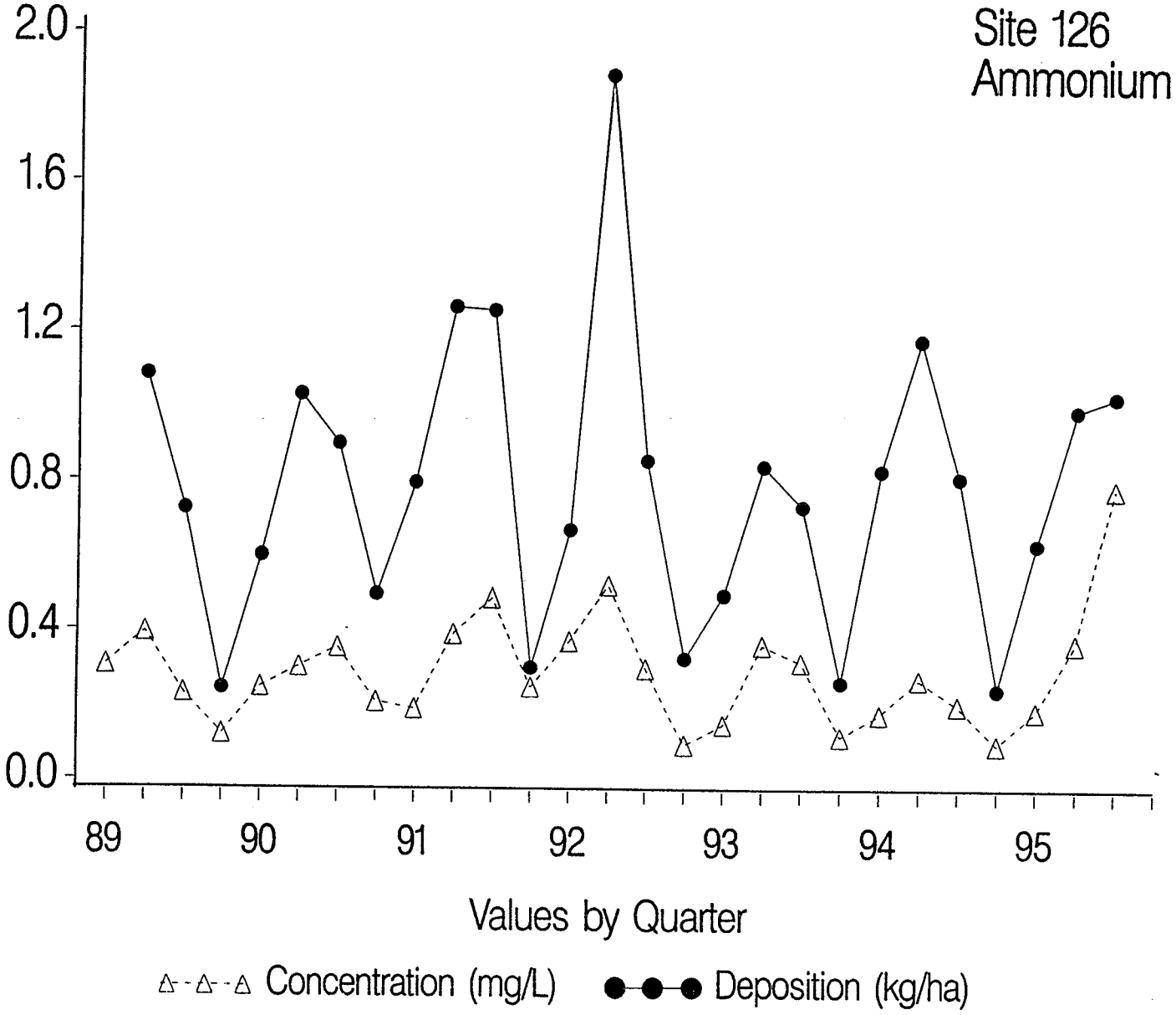


Figure 3-155. Quarterly average NH_4^+ concentrations and depositions for Site 126

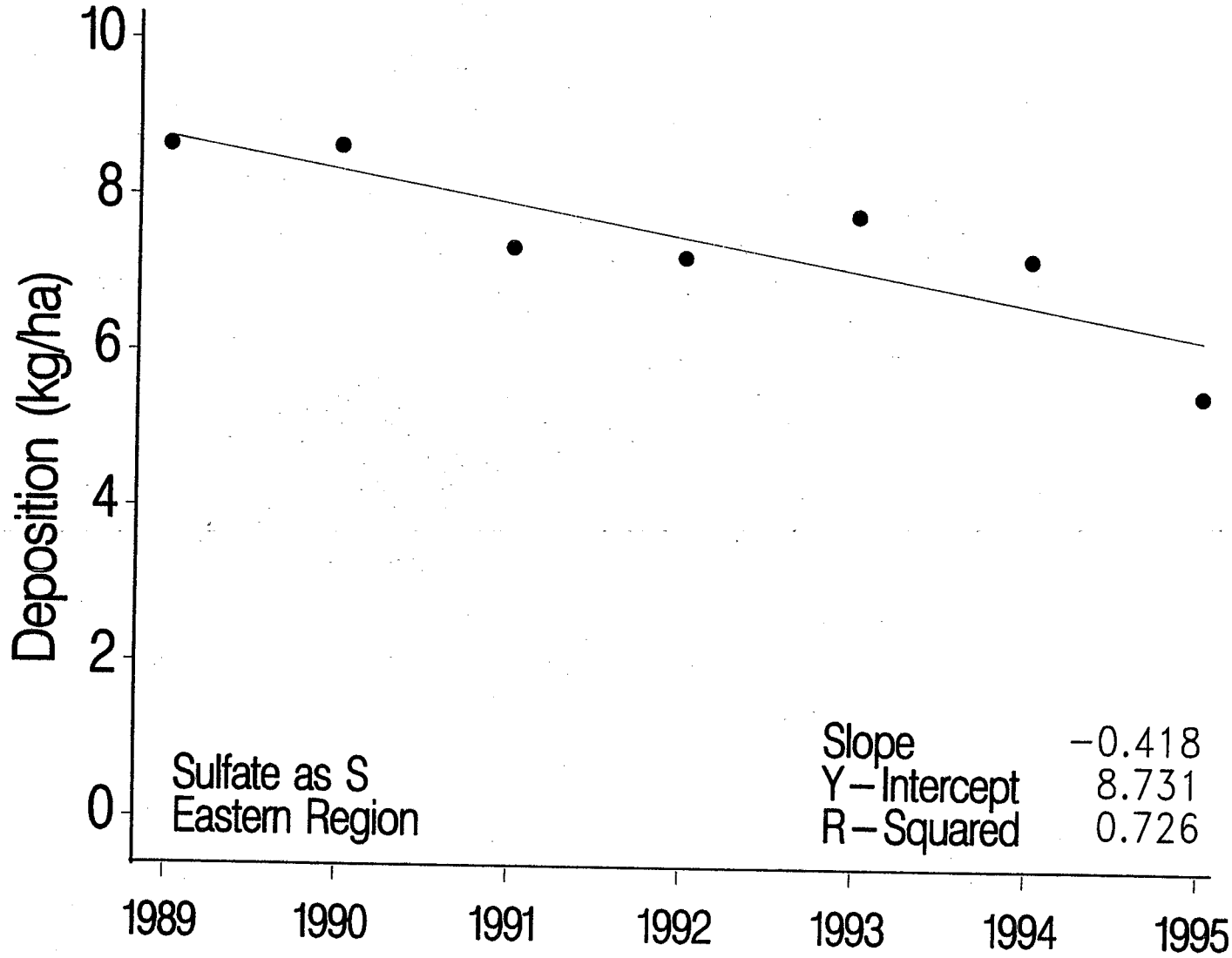


Figure 3-156. Linear regression analysis of sulfur in precipitation for the eastern subregion from 1989 to 1995

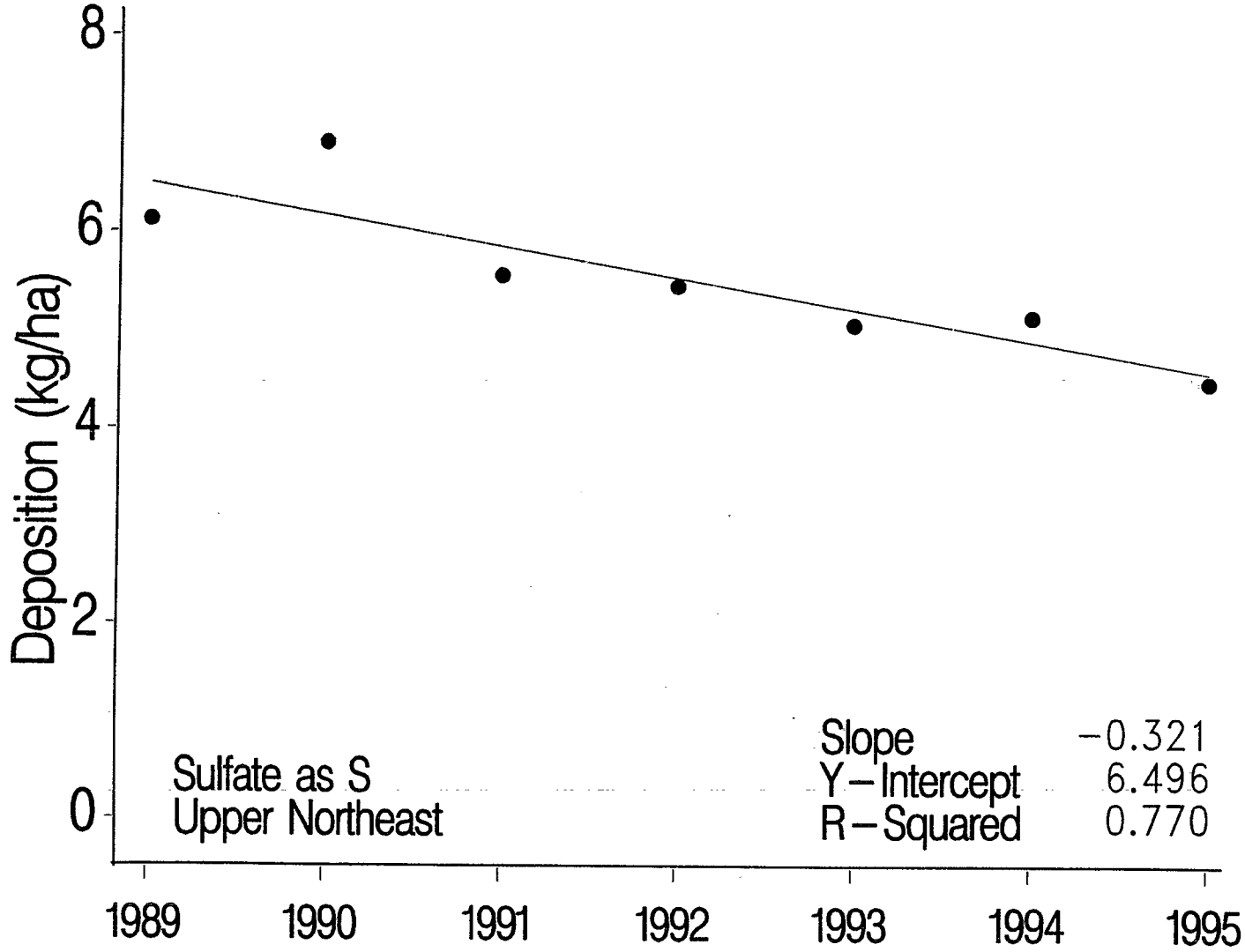


Figure 3-157. Linear regression analyses of sulfur in precipitation for the upper northeast subregion from 1989 to 1995

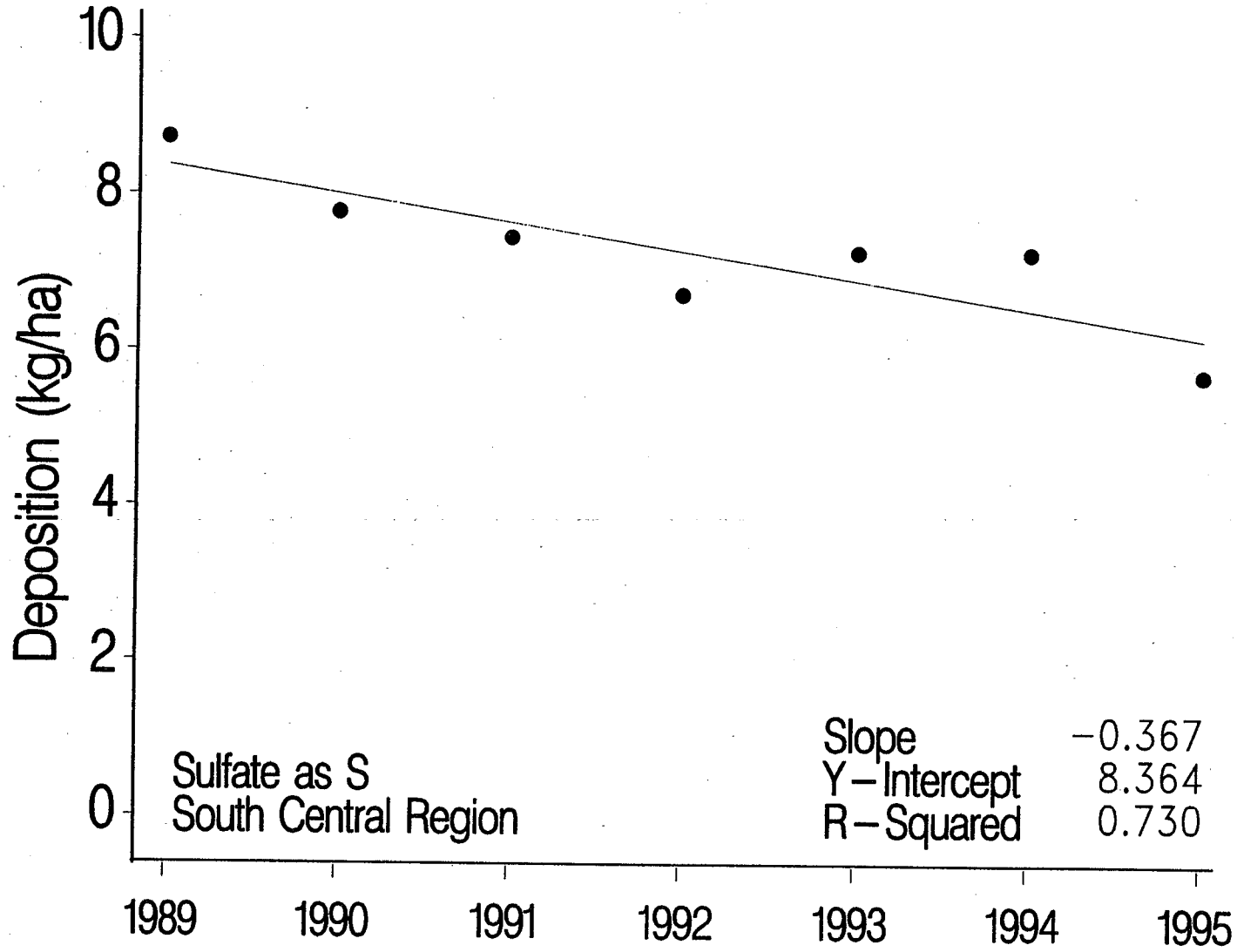


Figure 3-158. Linear regression analyses of sulfur in precipitation for the south-central subregion from 1989 to 1995

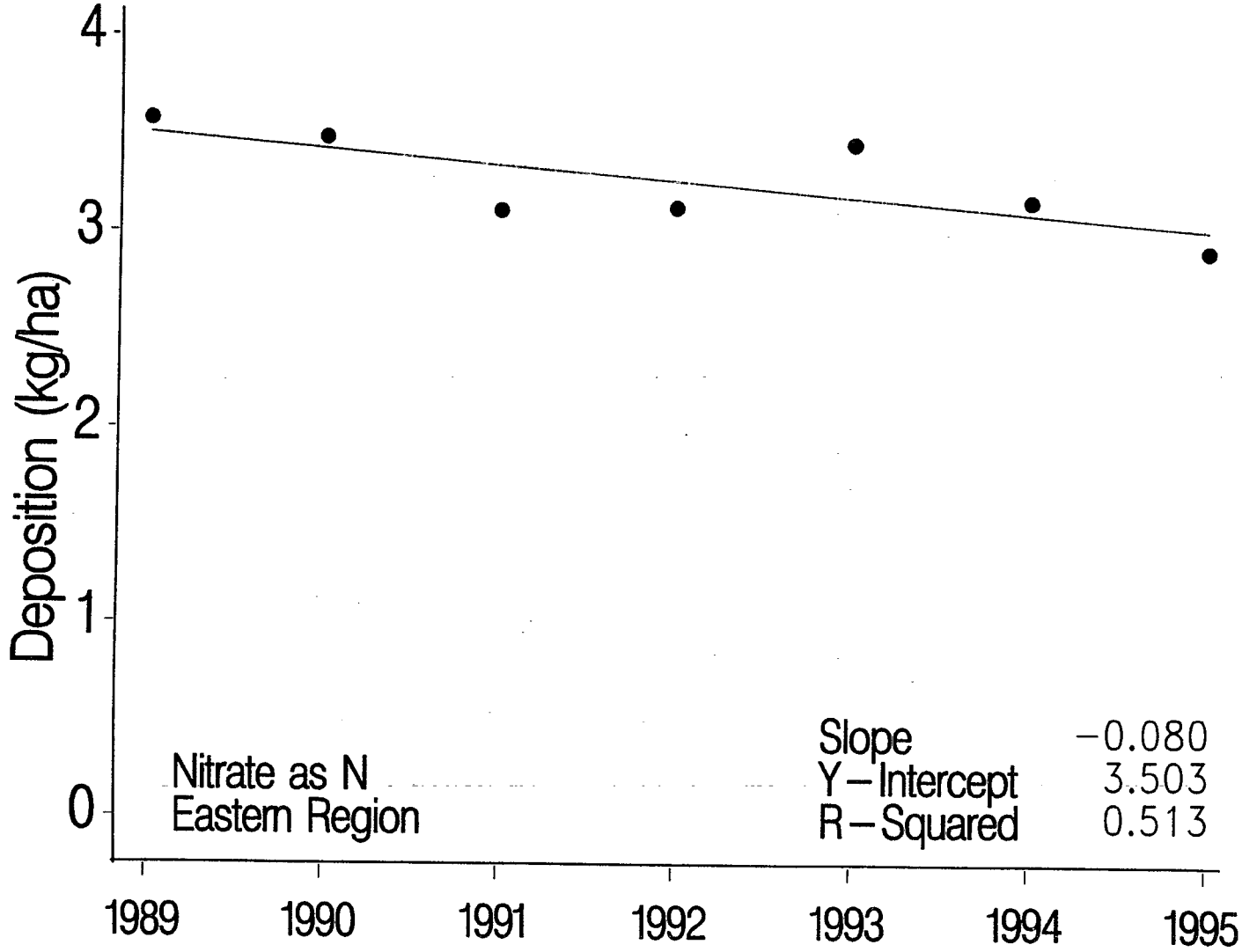


Figure 3-159. Linear regression analyses of nitrogen in precipitation for the eastern region from 1989 to 1995

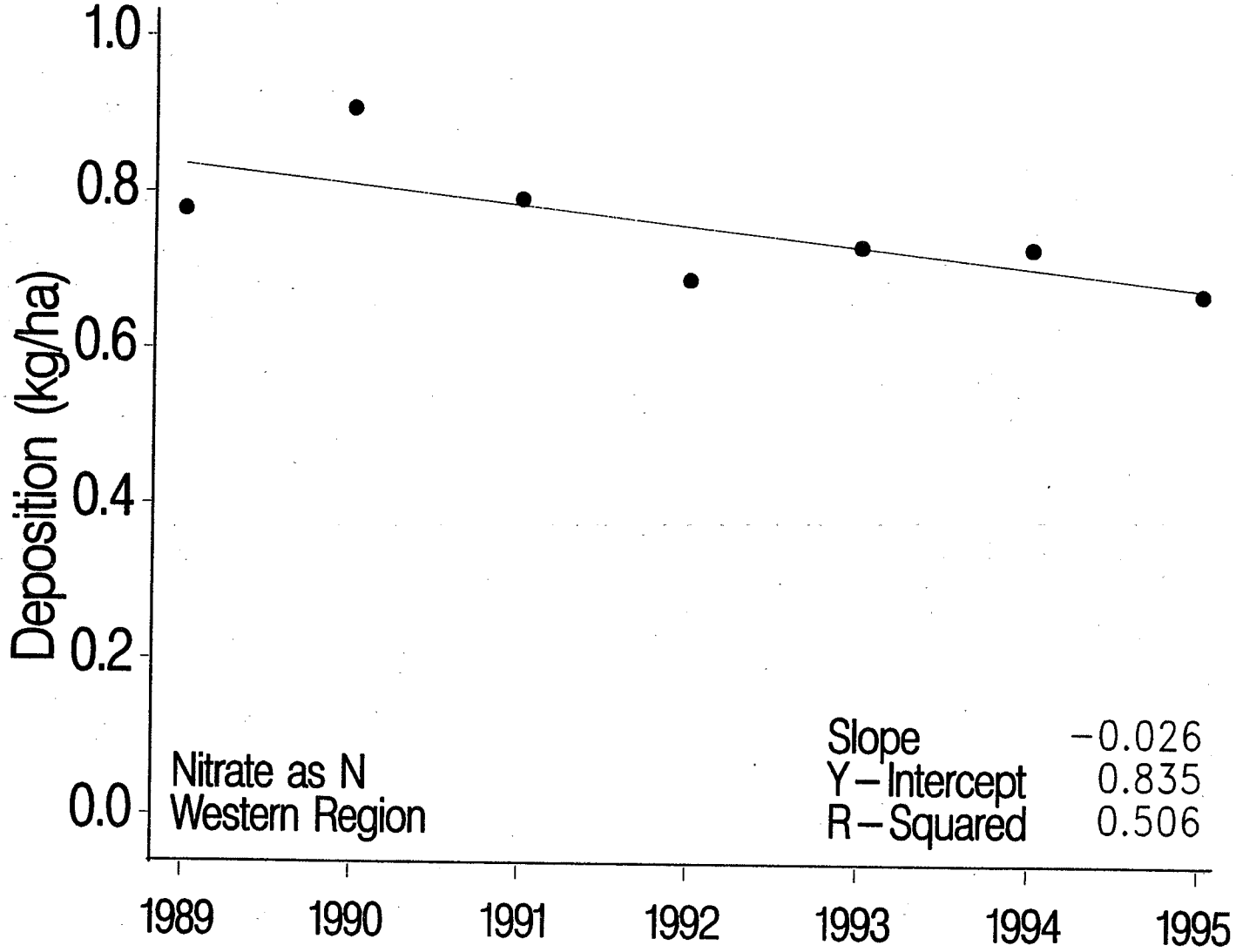


Figure 3-160. Linear regression analyses of nitrogen in precipitation for the western region from 1989 to 1995

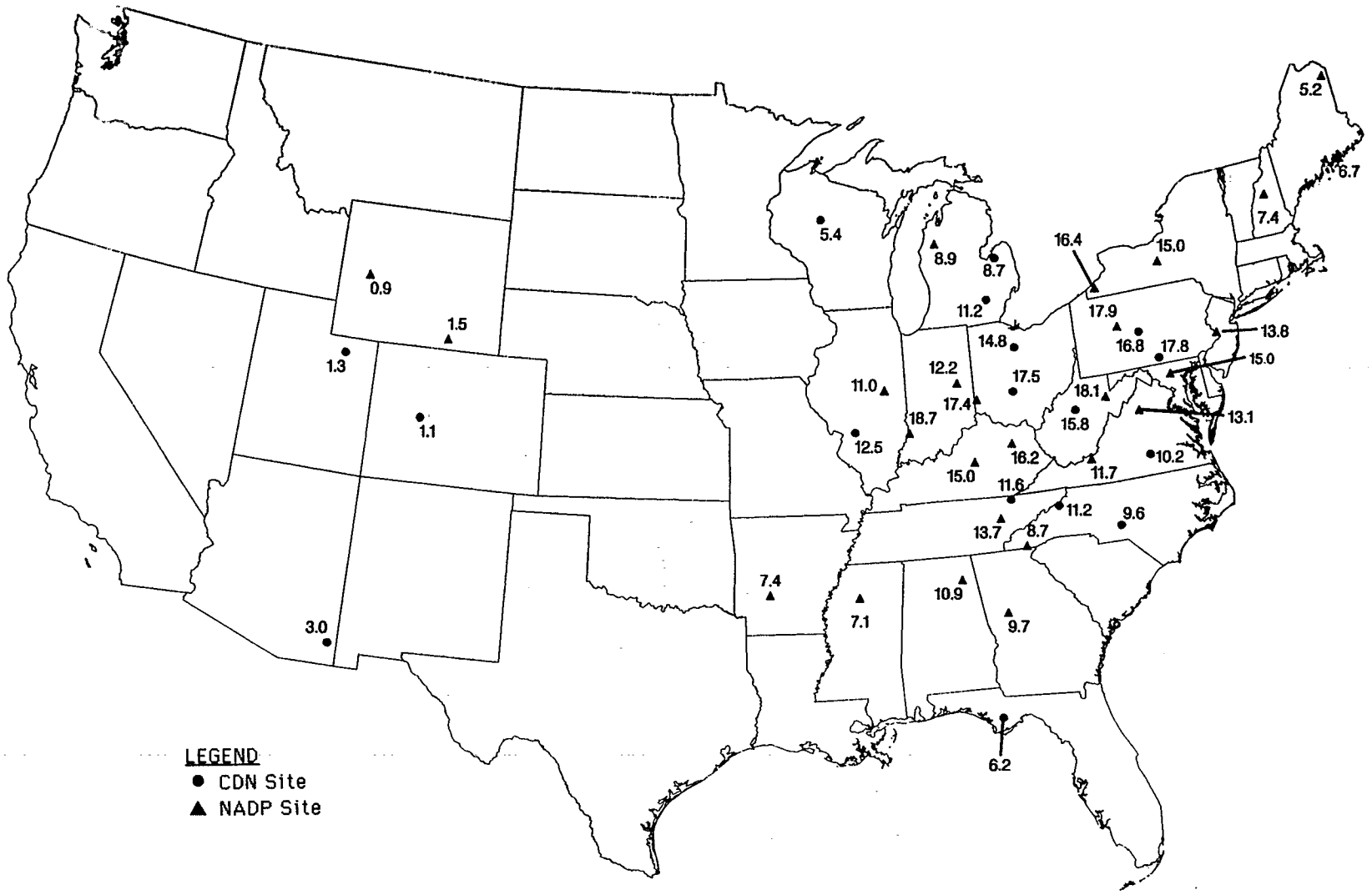


Figure 3-161. Annual average total sulfur depositions (kg/ha) averaged from 1989 to 1994

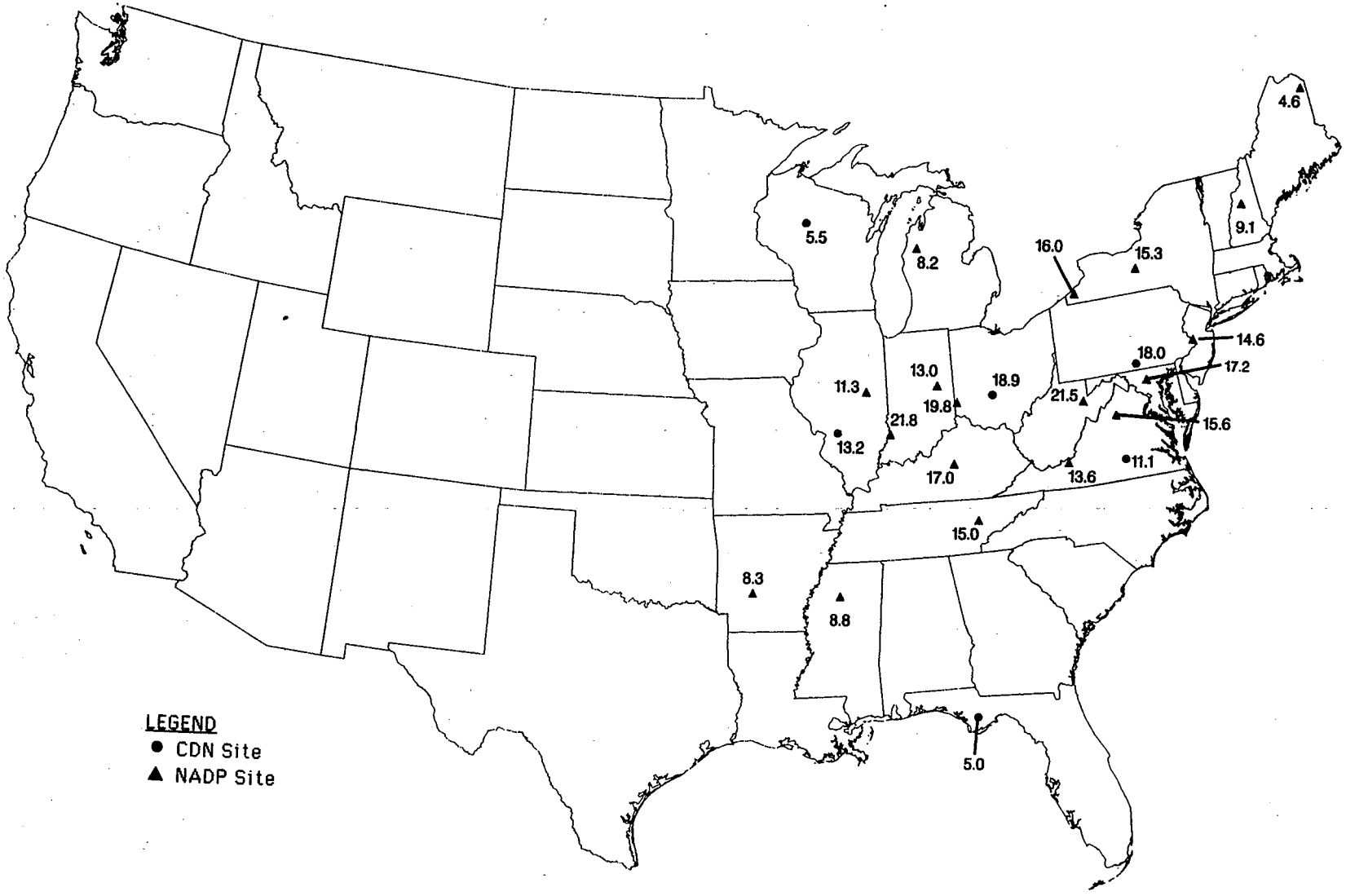


Figure 3-162. Annual average total sulfur depositions (kg/ha) for 1989

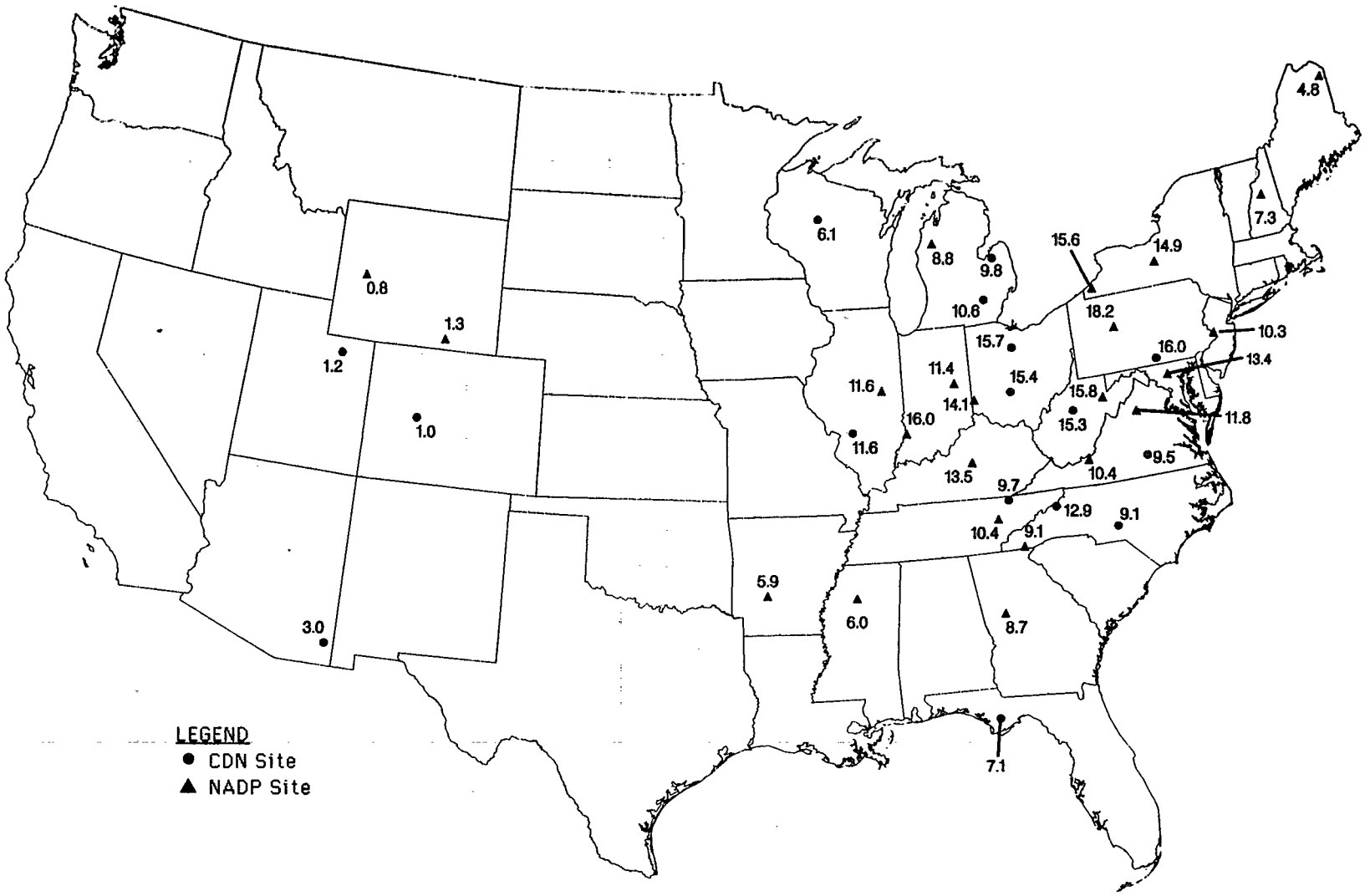


Figure 3-163. Annual average total sulfur depositions (kg/ha) for 1992

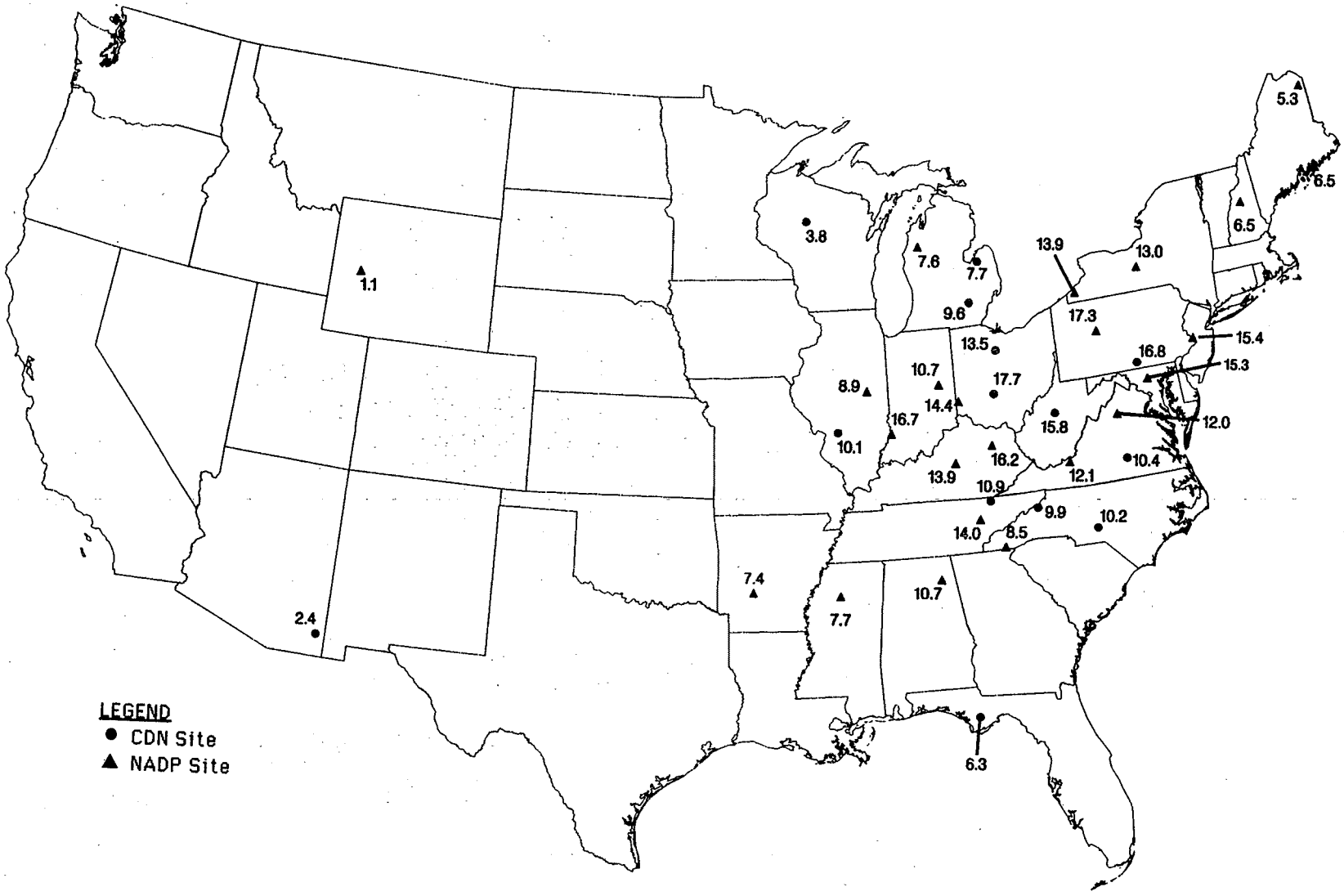


Figure 3-164. Annual average total sulfur depositions (kg/ha) for 1994

Figure 3-165. Percentages of dry sulfur deposition for the 6-year average (1989 to 1994)

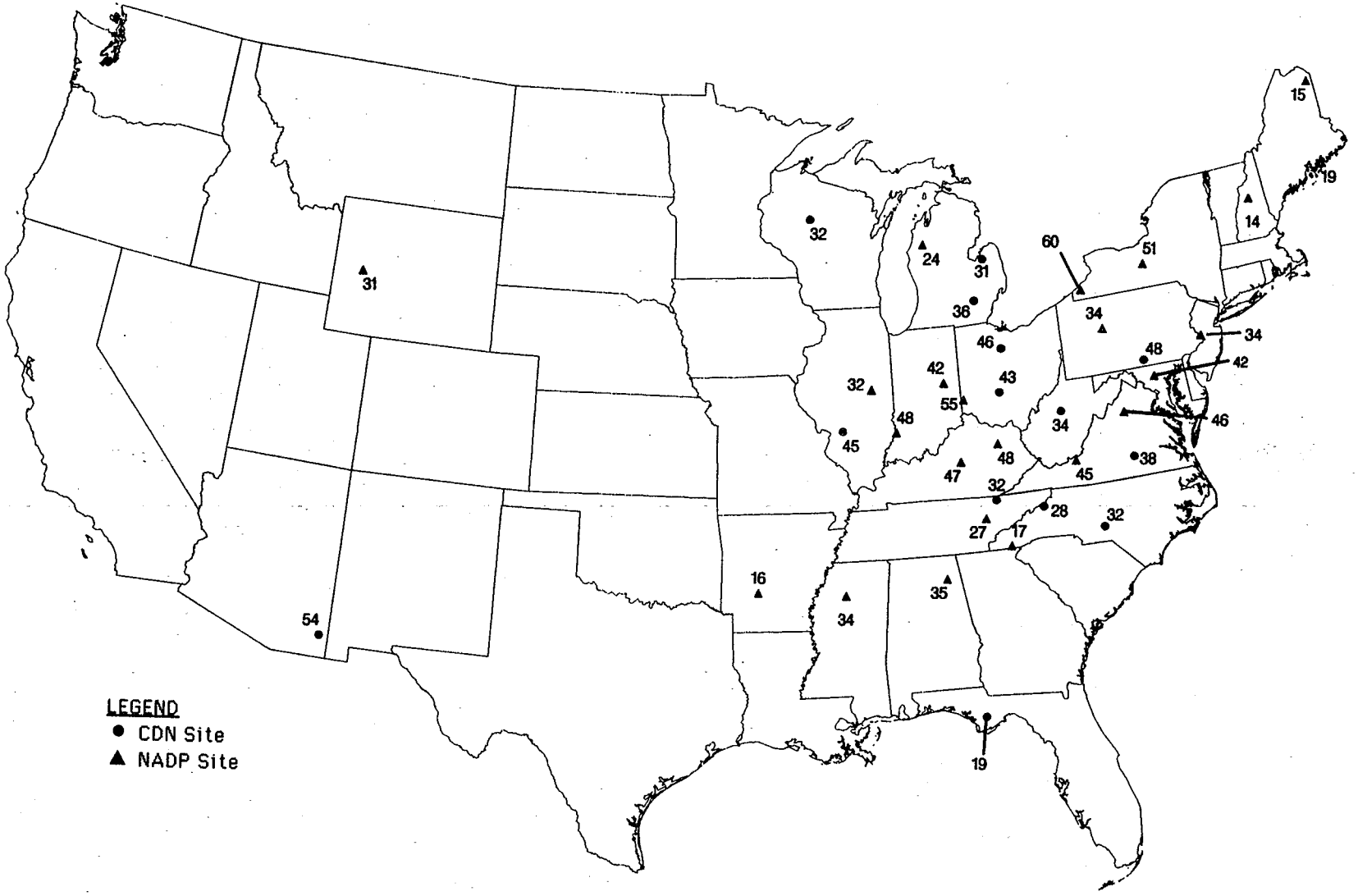


Figure 3-166. Percentages of dry sulfur deposition for 1994

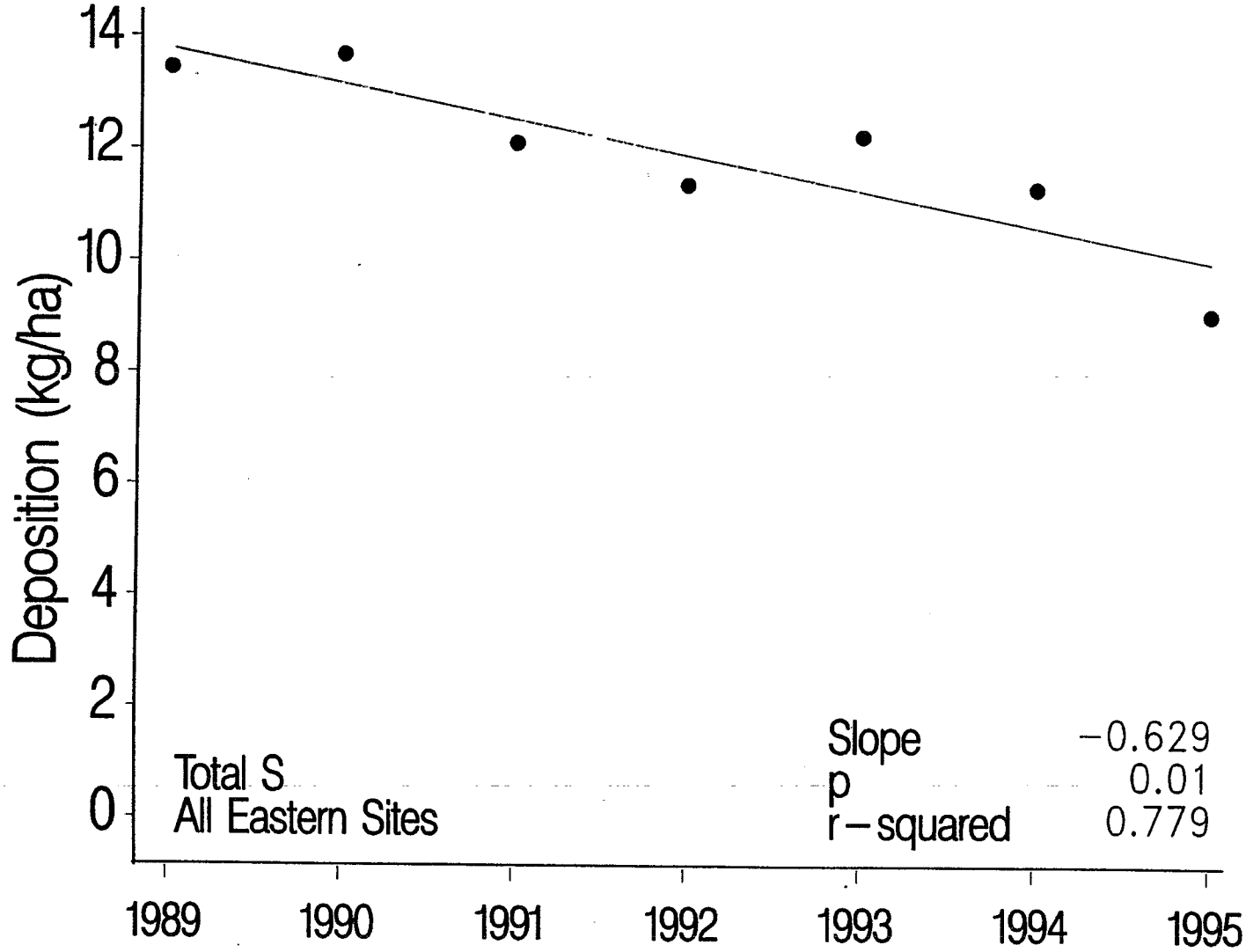


Figure 3-167. Linear regressions of total sulfur depositions versus year for all eastern sites combined

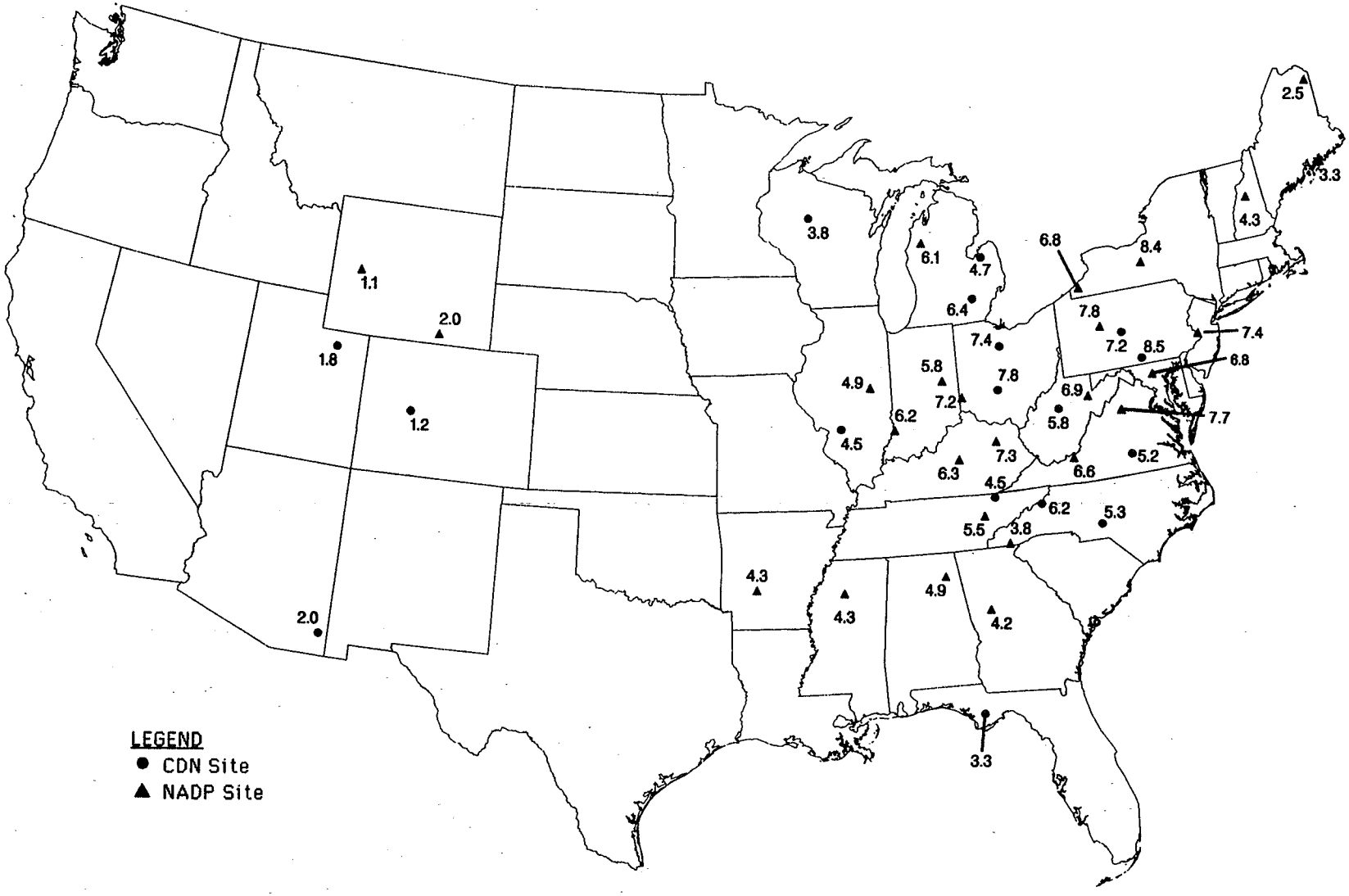


Figure 3-168. Annual average total nitrogen depositions (kg/ha) averaged from 1989 to 1994

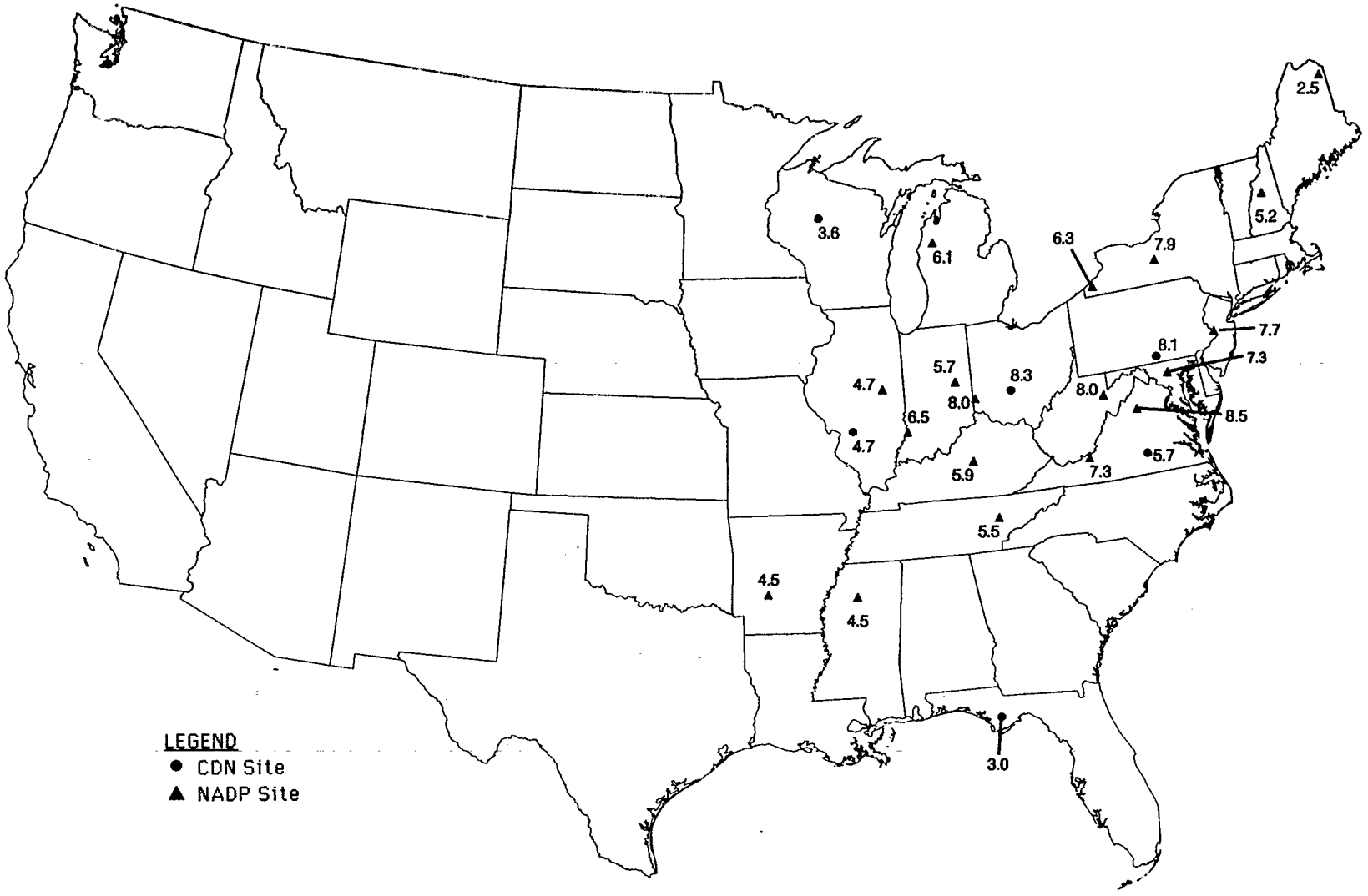


Figure 3-169. Annual average total nitrogen depositions (kg/ha) for 1989

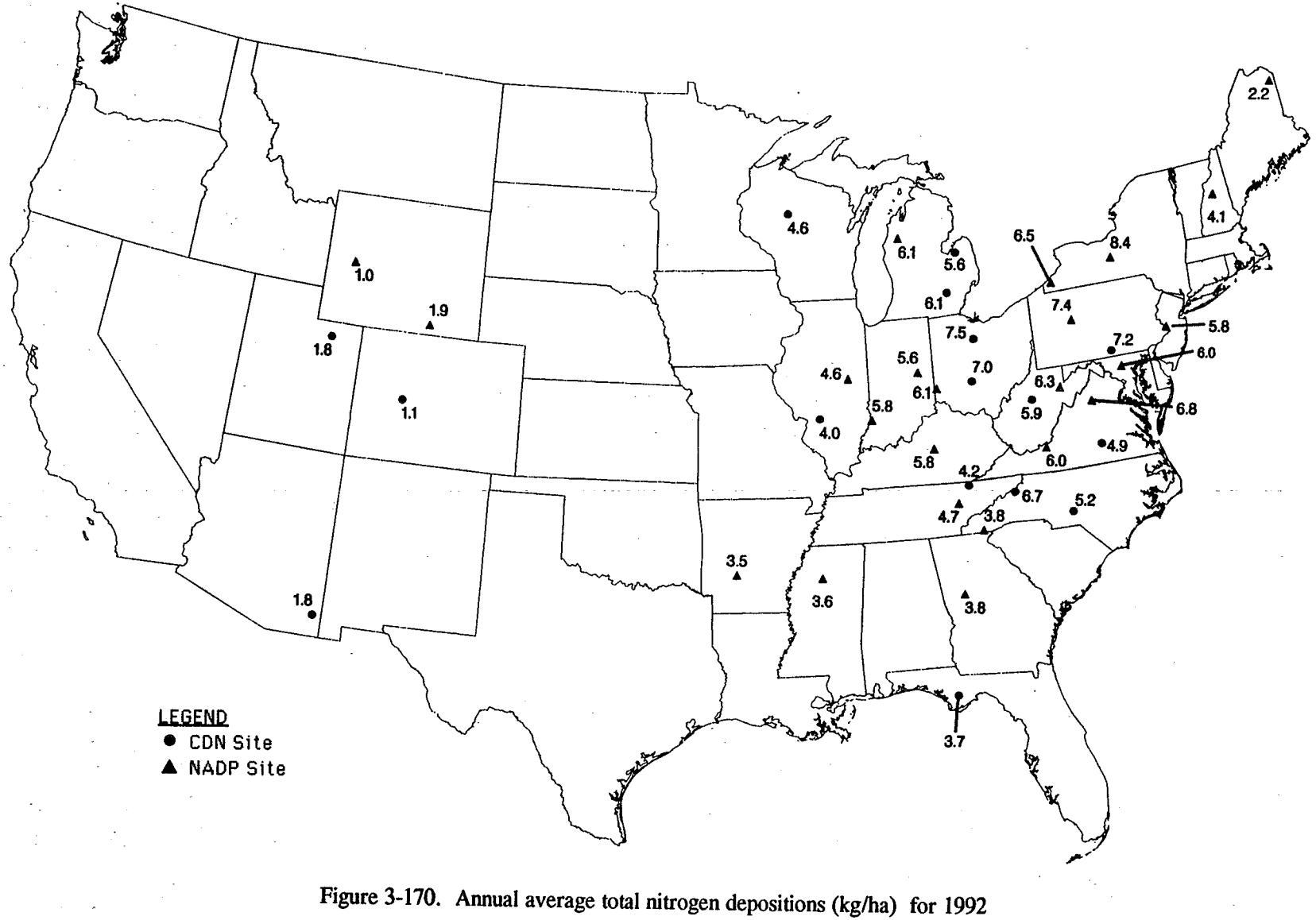


Figure 3-170. Annual average total nitrogen depositions (kg/ha) for 1992

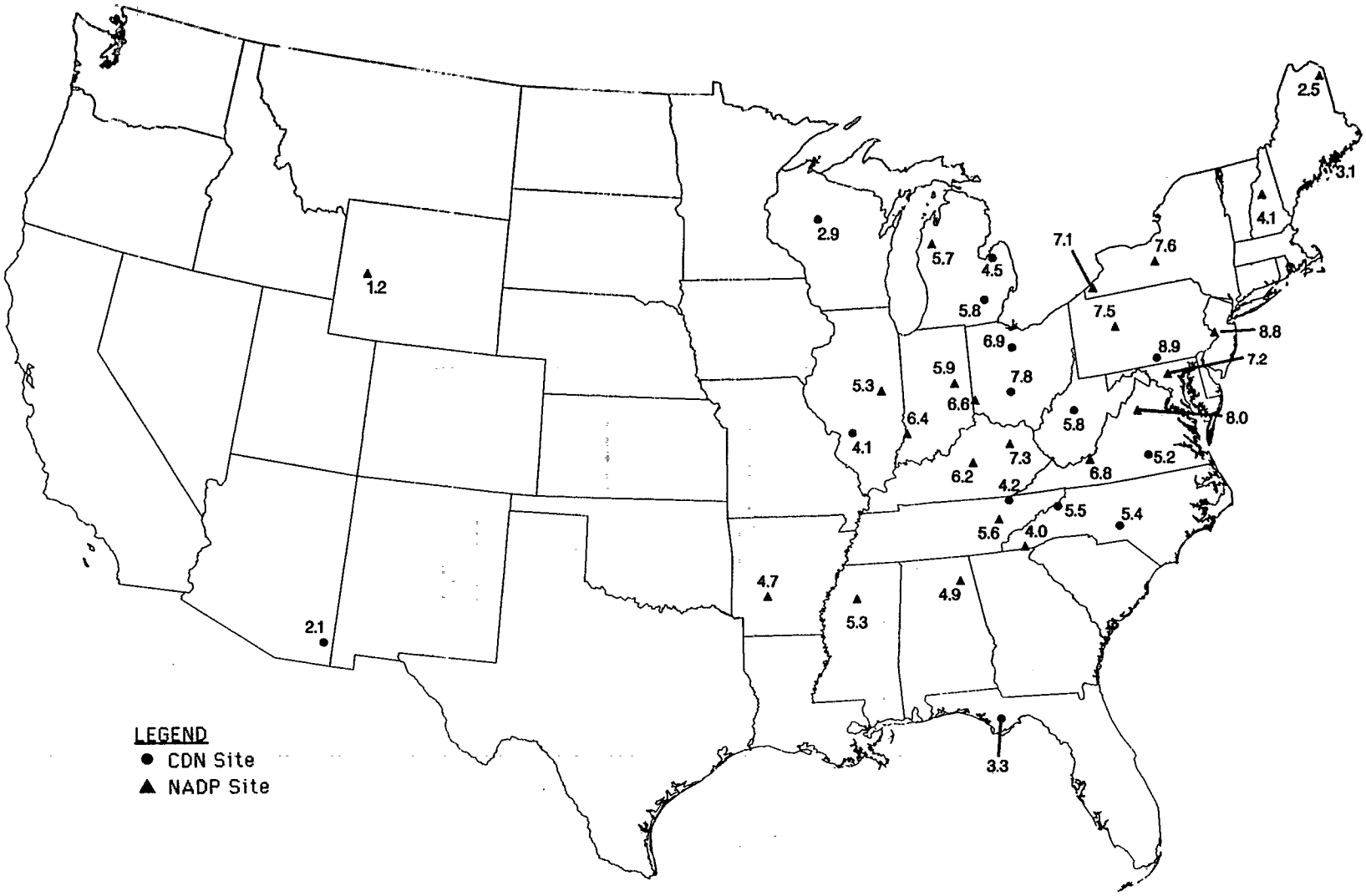


Figure 3-171. Annual average total nitrogen depositions (kg/ha) for 1994

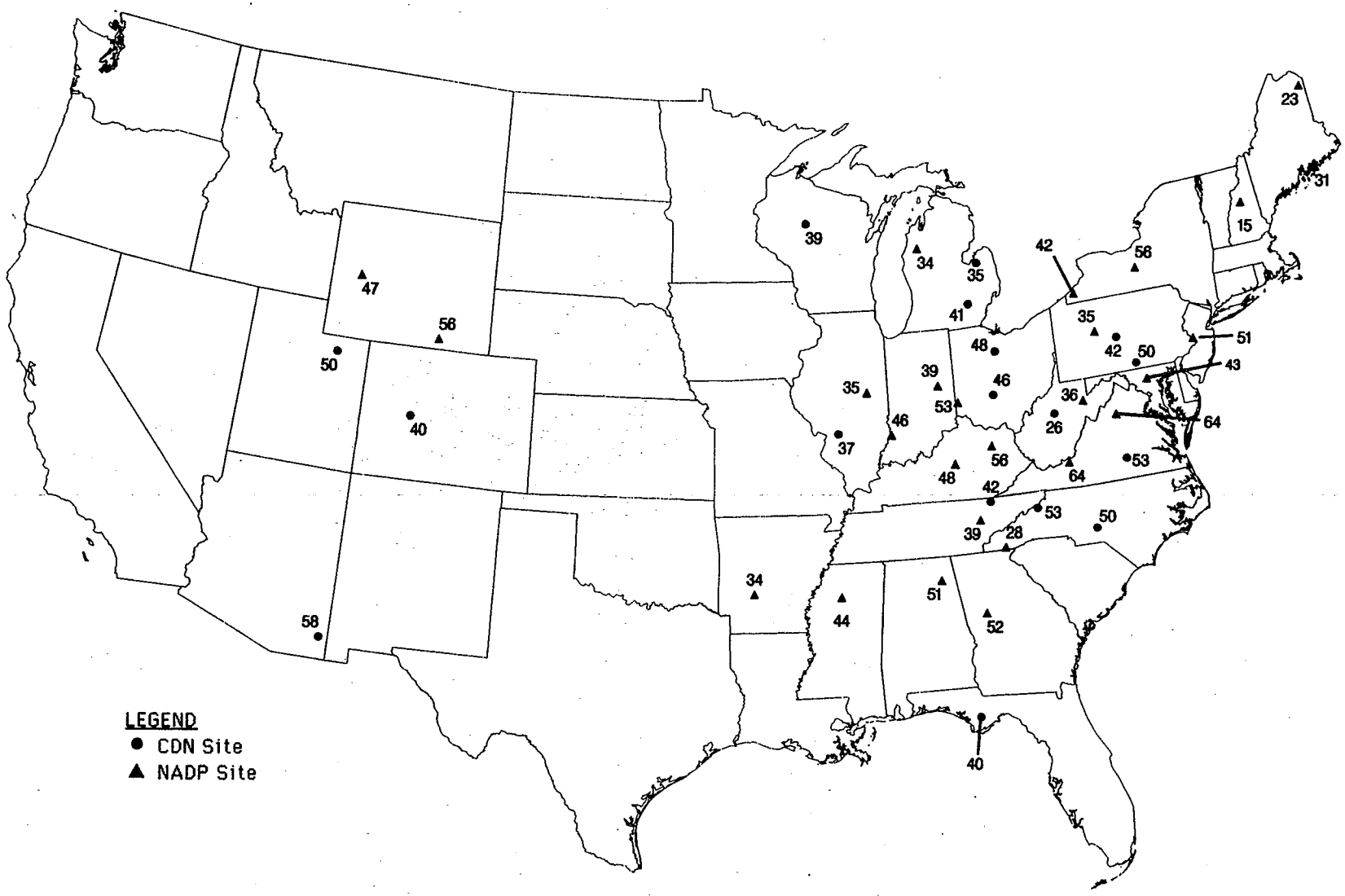


Figure 3-172. Percentages of dry nitrogen deposition for the 6-year average (1989 to 1994)

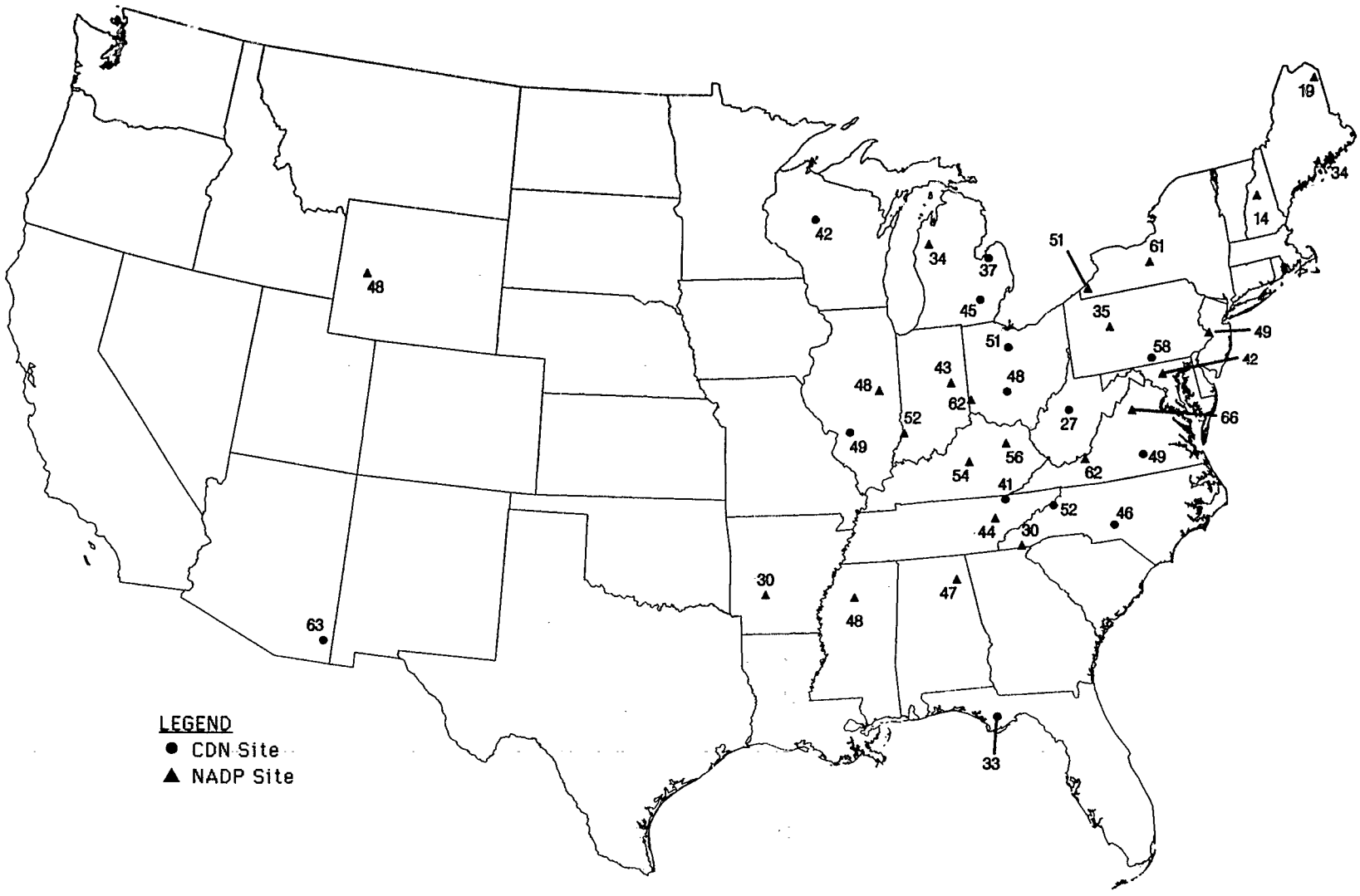


Figure 3-173. Percentages of dry nitrogen deposition for 1994

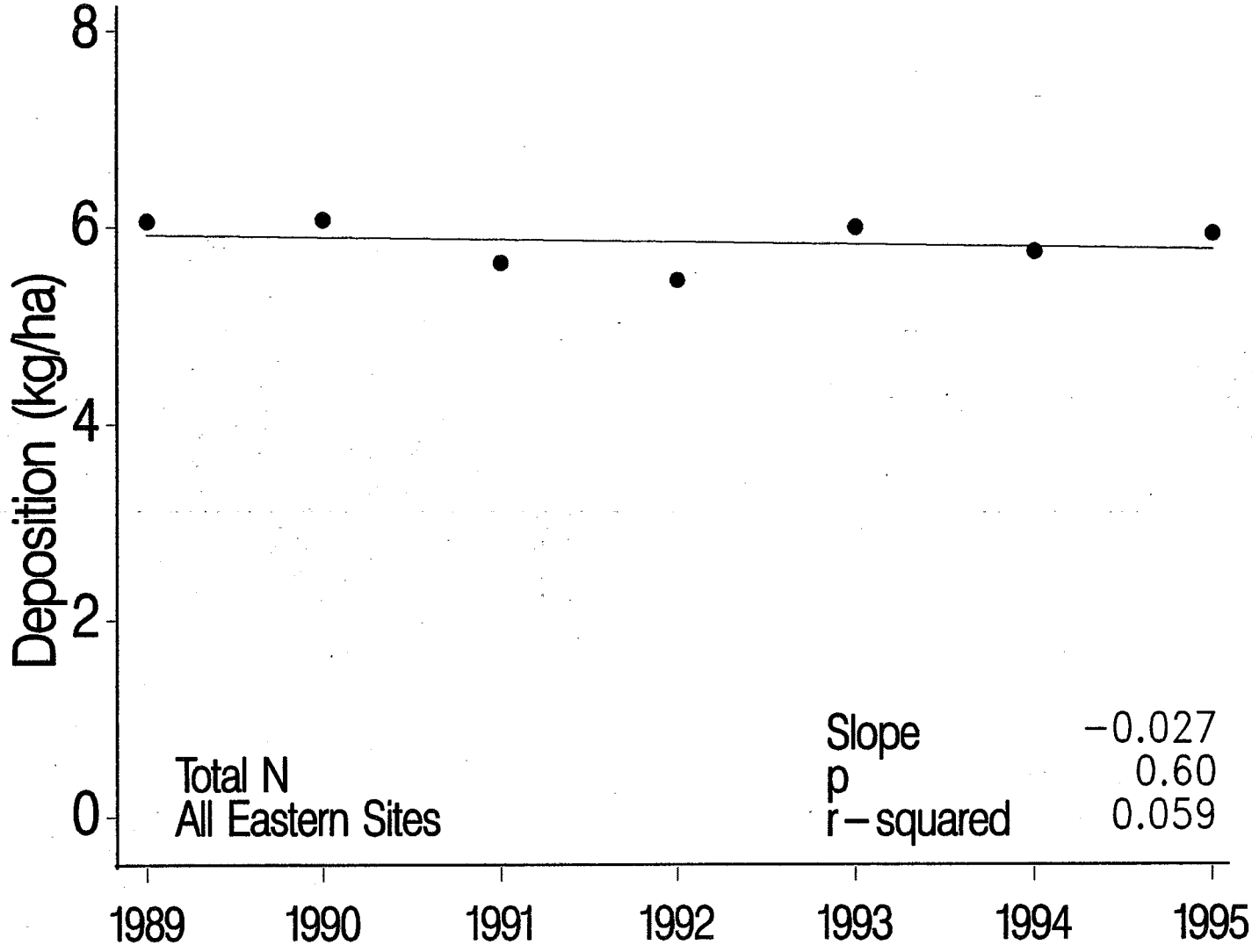


Figure 3-174. Linear regressions of total nitrogen depositions versus year for all eastern sites combined

Figure 3-175. Number of hourly O_3 values greater than 124 ppb for 1988/(1989 to 1995)

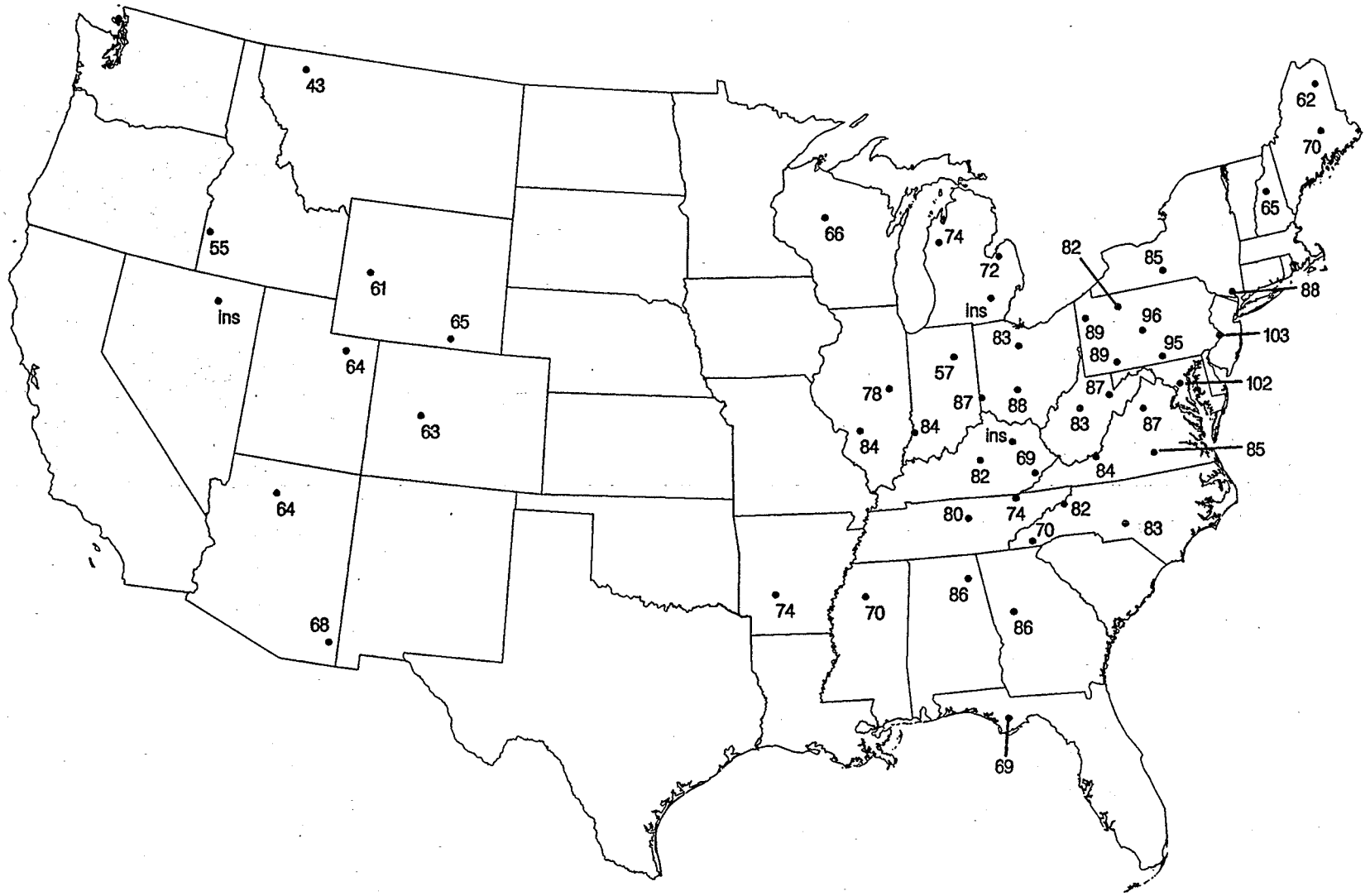


Figure 3-176. Fourth highest rolling 8-hour average O_3 concentrations for 1993

Figure 3-177. Fourth highest rolling 8-hour average O_3 concentrations for 1994

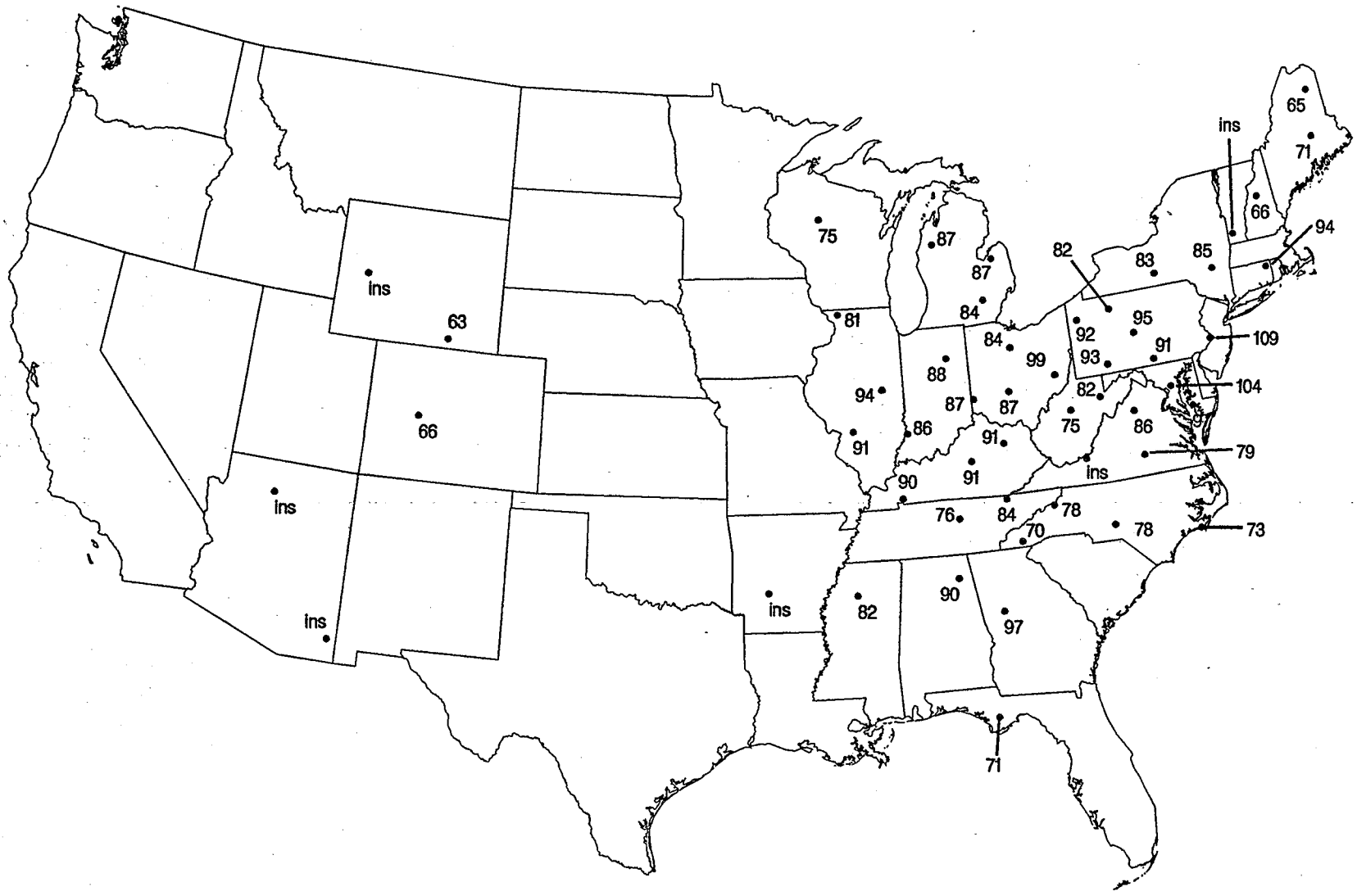


Figure 3-178. Fourth highest rolling 8-hour average O_3 concentrations for 1995

Figure 3-179. Fourth highest rolling 8-hour average O_3 concentrations for 1993 to 1995 (3 year average)

Figure 3-180. Maximum/minimum number of days with 8-hour O_3 concentrations ≥80 ppm, 1988 to 1995

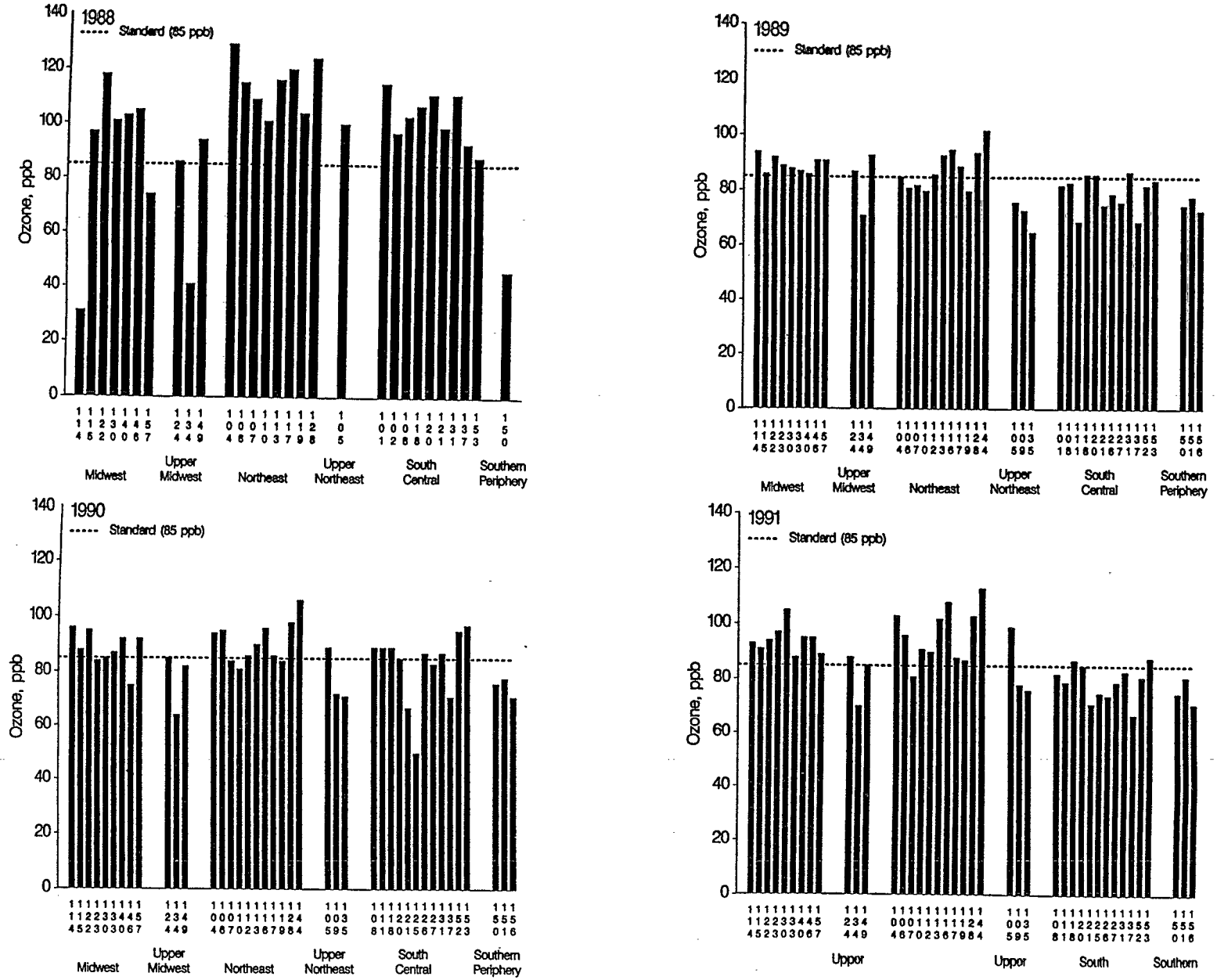


Figure 3-181. Fourth highest 8-hour concentration for each site by subregion for 1988 to 1991

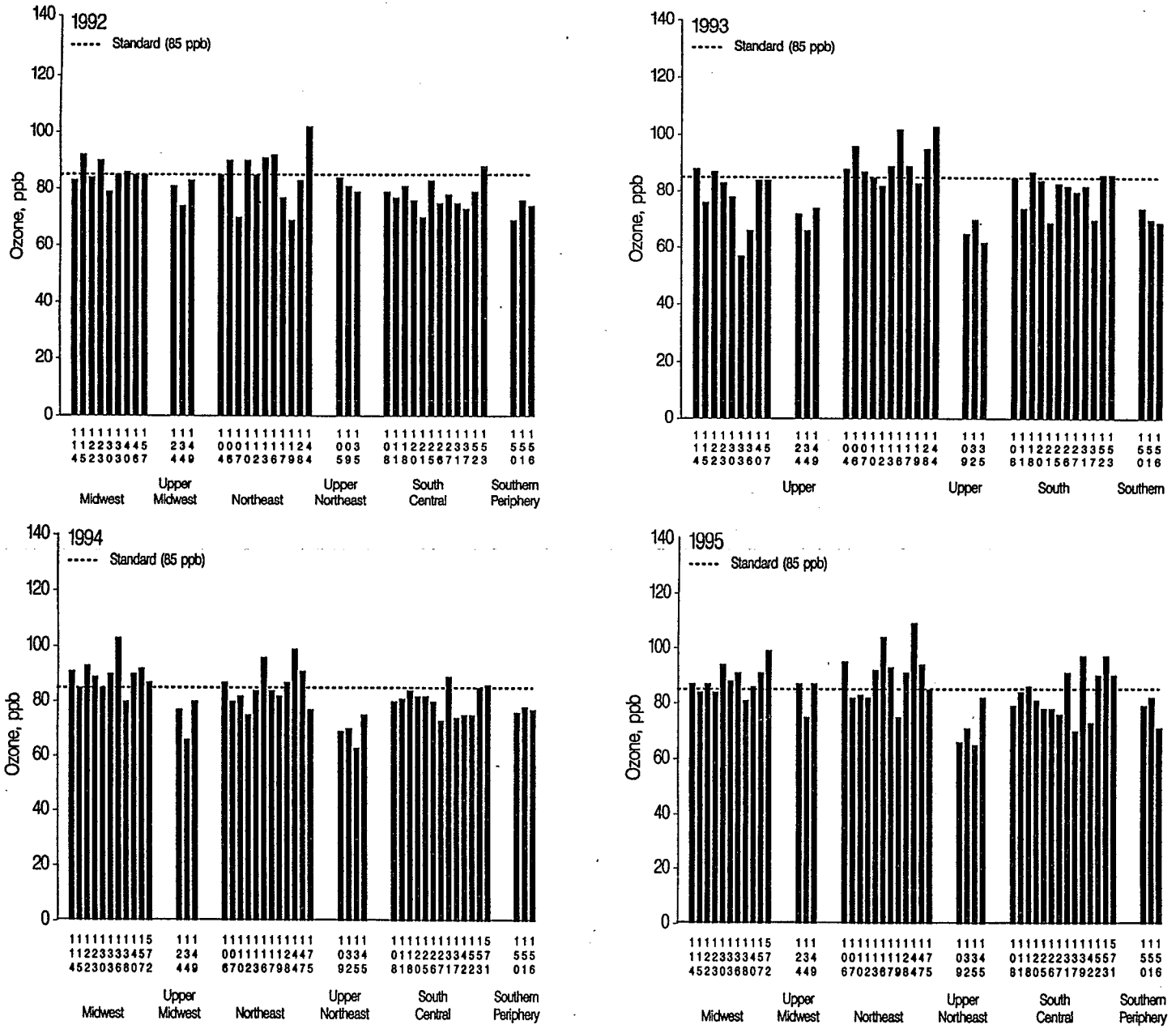


Figure 3-182. Fourth highest 8-hour concentration for each site by subregion for 1992 to 1995

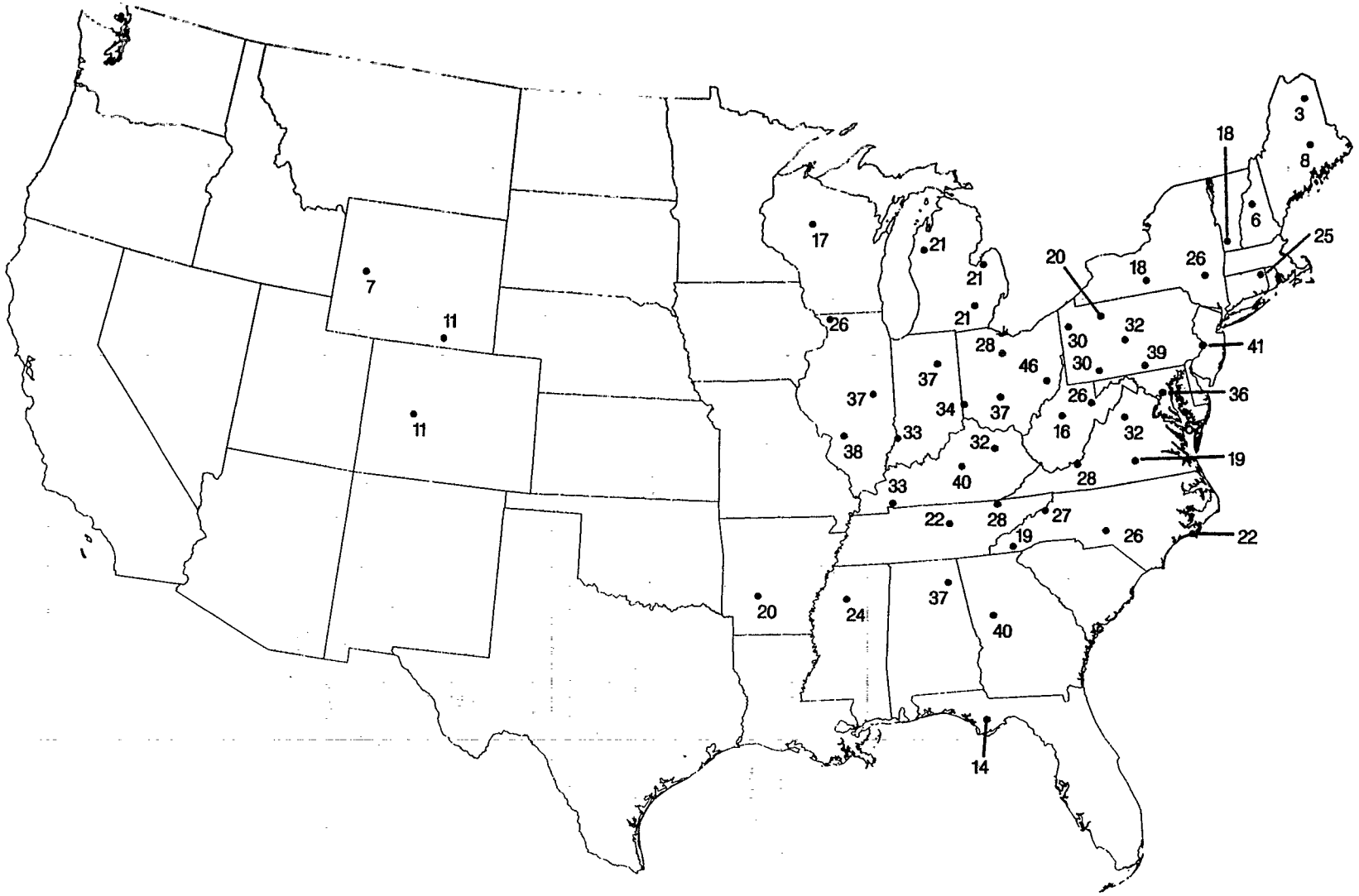


Figure 3-183. Maximum SUM06 O_3 values for 1995

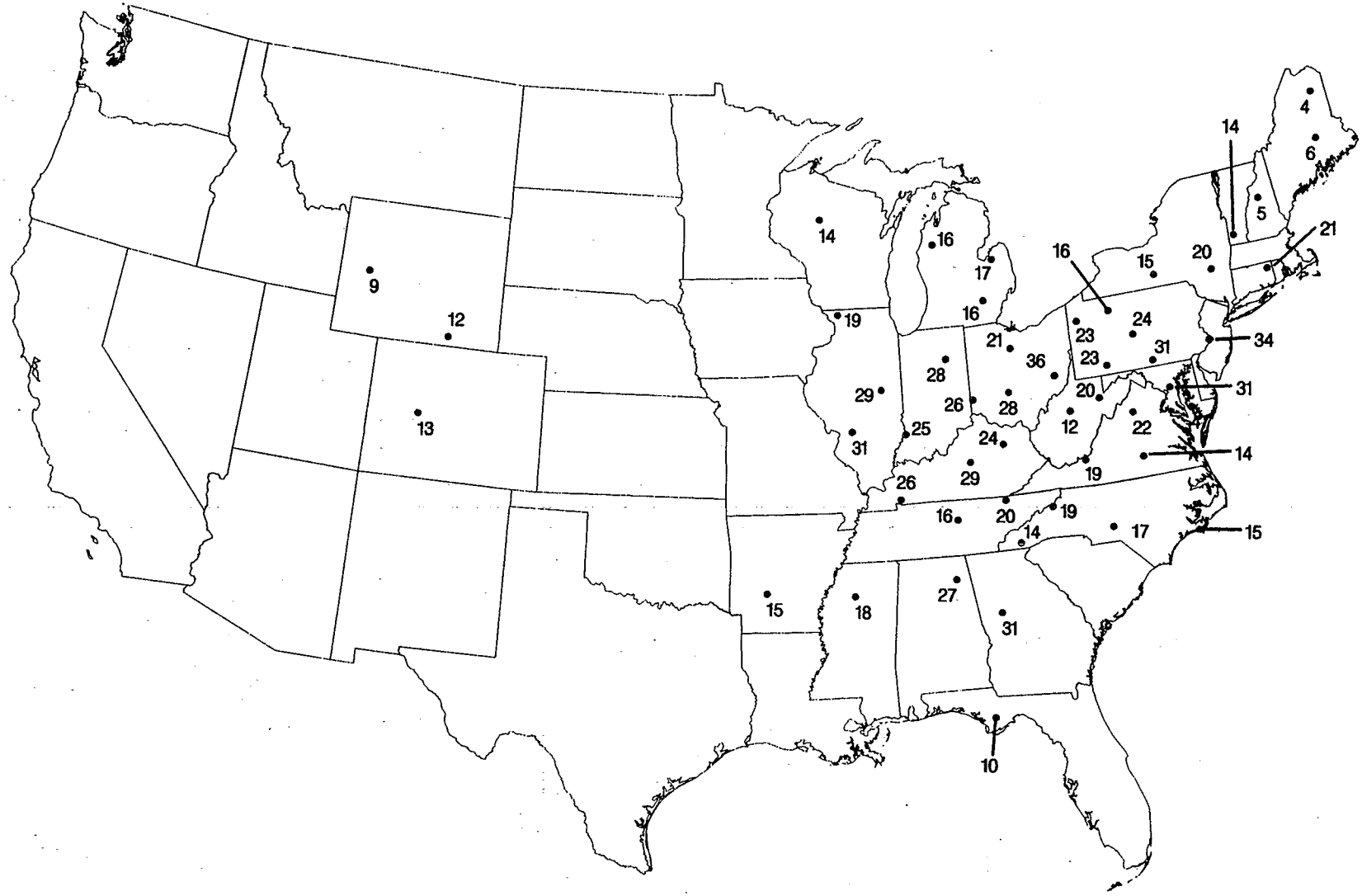
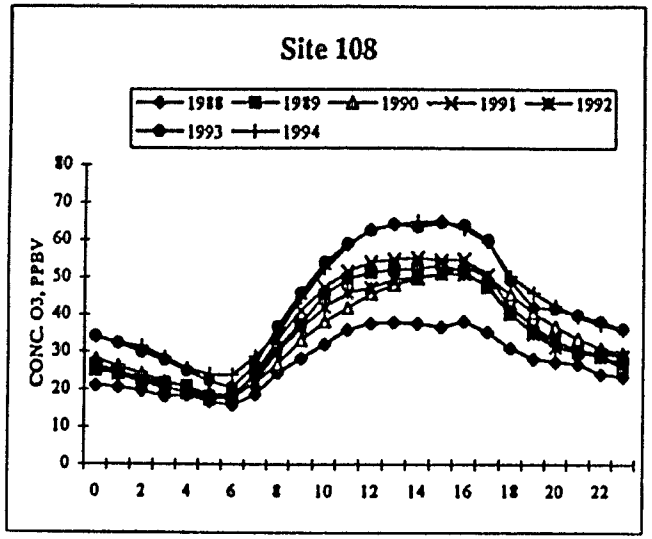
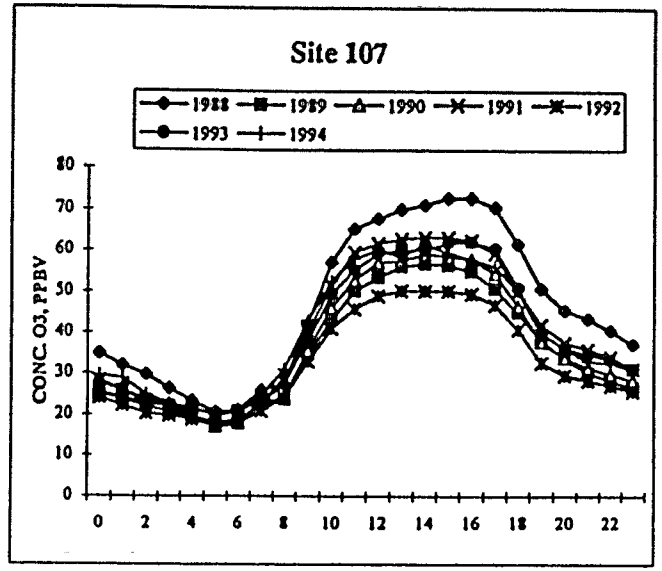


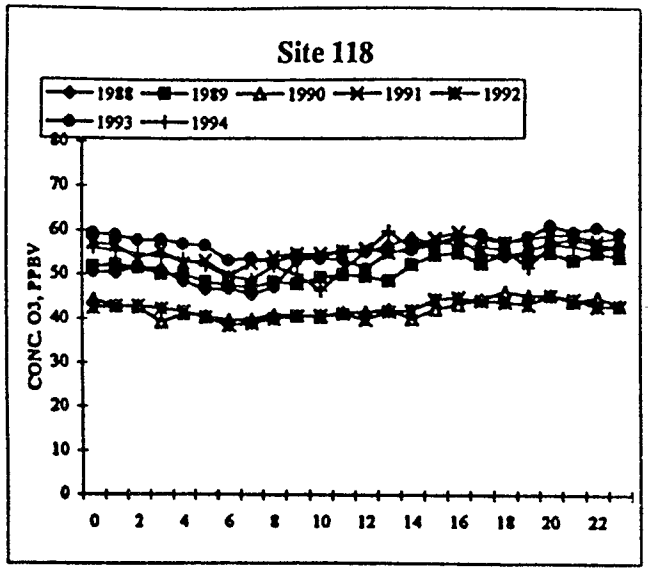
Figure 3-184. Maximum W126 (rolling 3 month) O_3 values for 1995



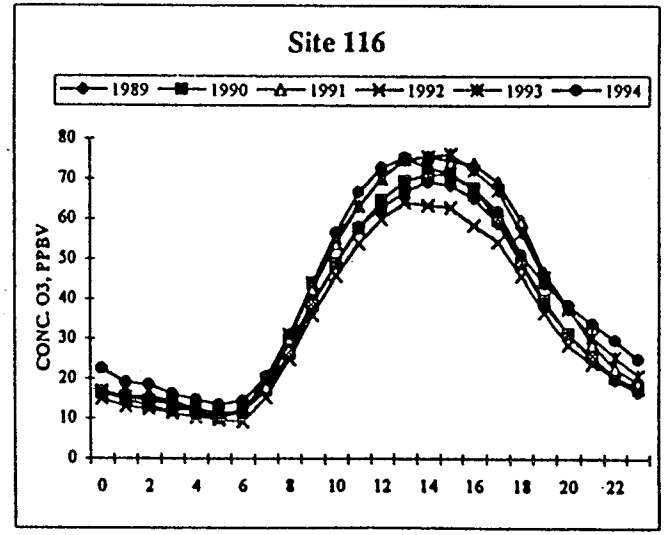
(a) Prince Edward, VA
(Rolling terrain site)



(b) Parson, WV
(Complex terrain site)



(a) Big Meadows, VA
(Mountaintop site)



(d) Beltsville, MD
(Semi-urban site)

Figure 3-185. Hourly average O_3 concentrations for a rolling terrain site (Prince Edward, VA), a complex terrain site (Parsons, WV), a mountaintop site (Big Meadows, VA), and a suburban site (Beltsville, MD)

Figure 3-186. Locations of MADPro sites

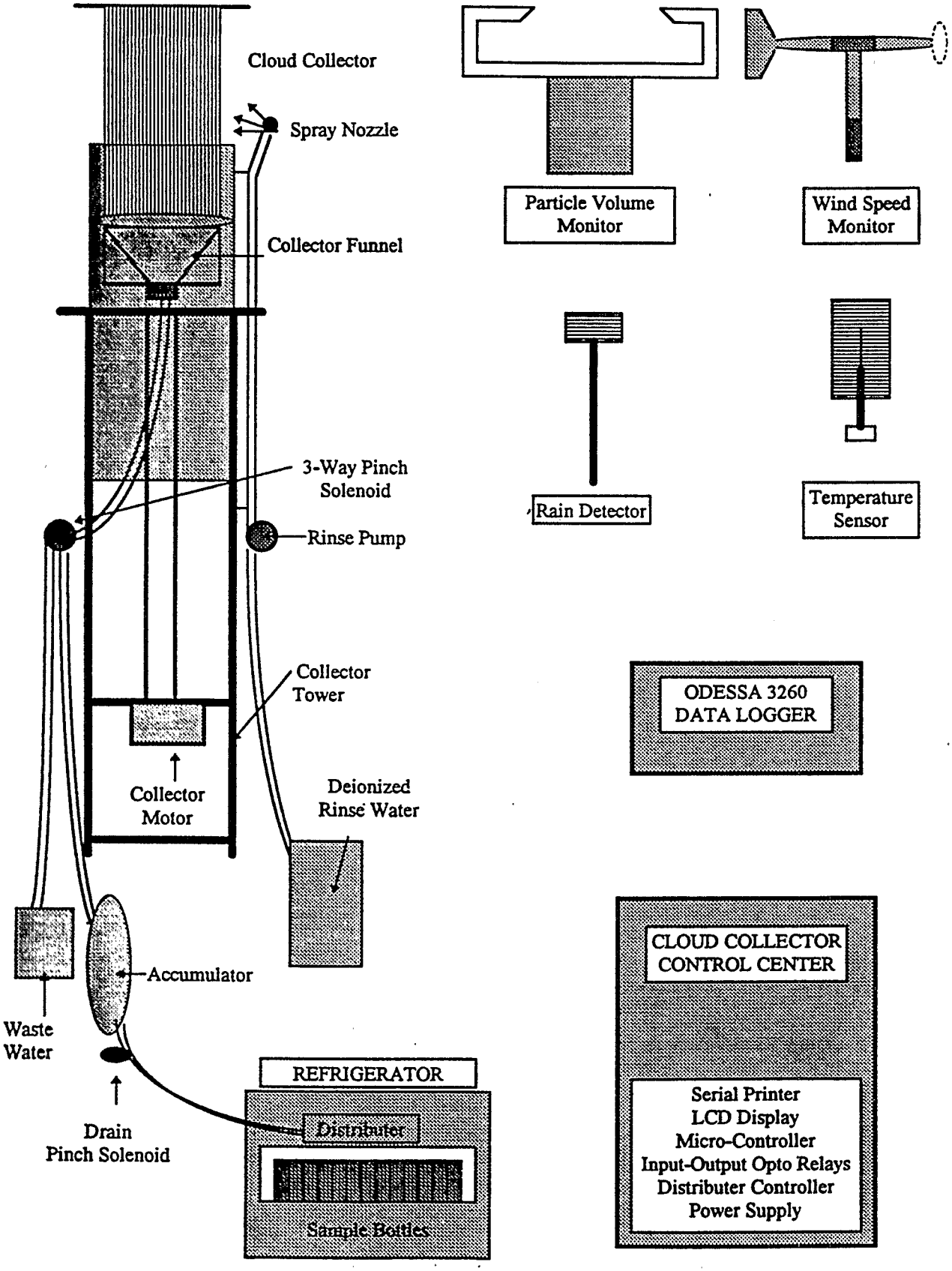


Figure 3-187. Diagram of the MADPro cloudwater sampling system

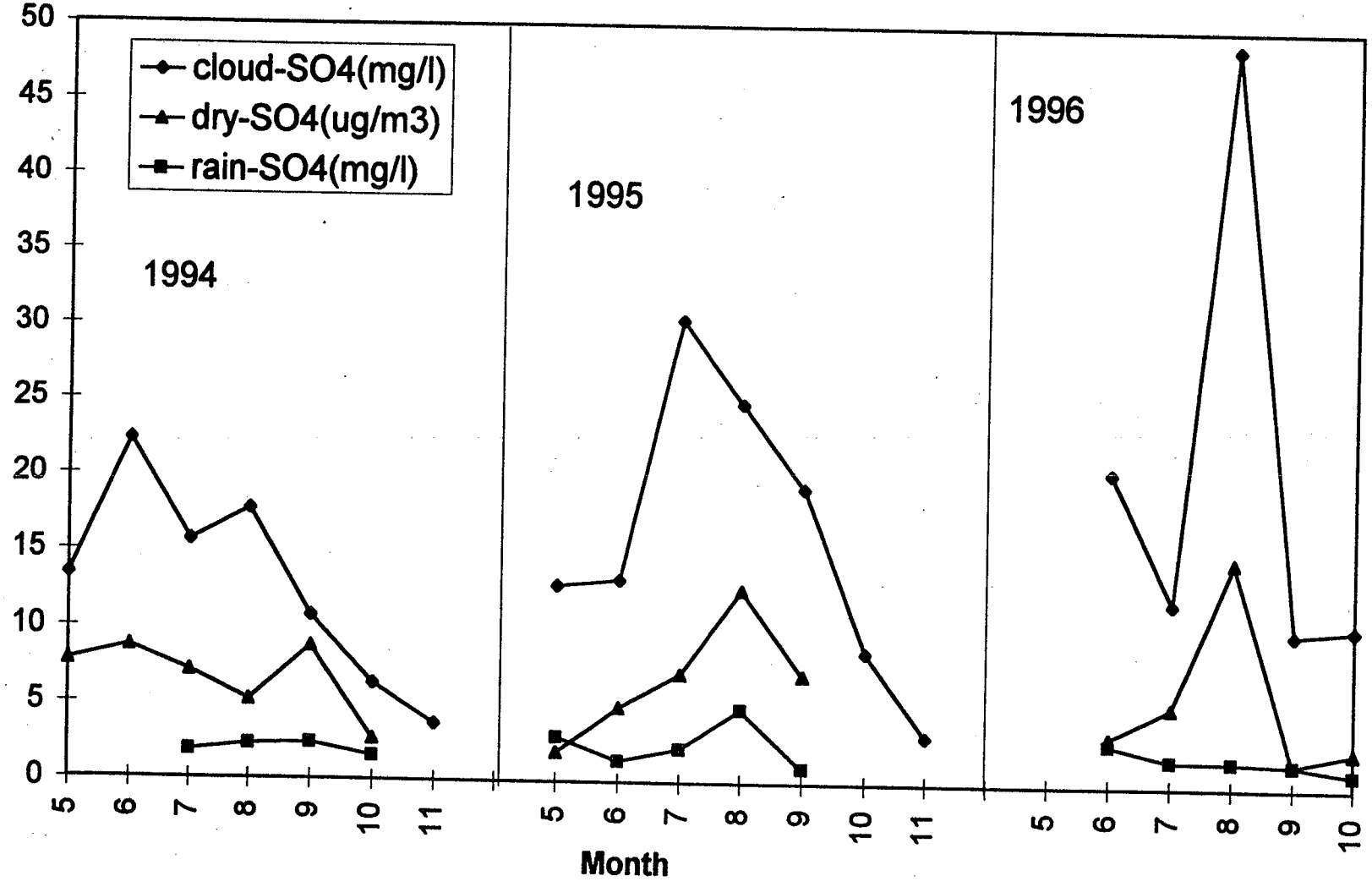


Figure 3-188. Mean monthly SO_4^{2-} concentrations ($\mu g/m^3$) found in dry air and in rainwater and cloudwater (mg/L) at Whitetop Mountain, VA, from 1994 to 1996

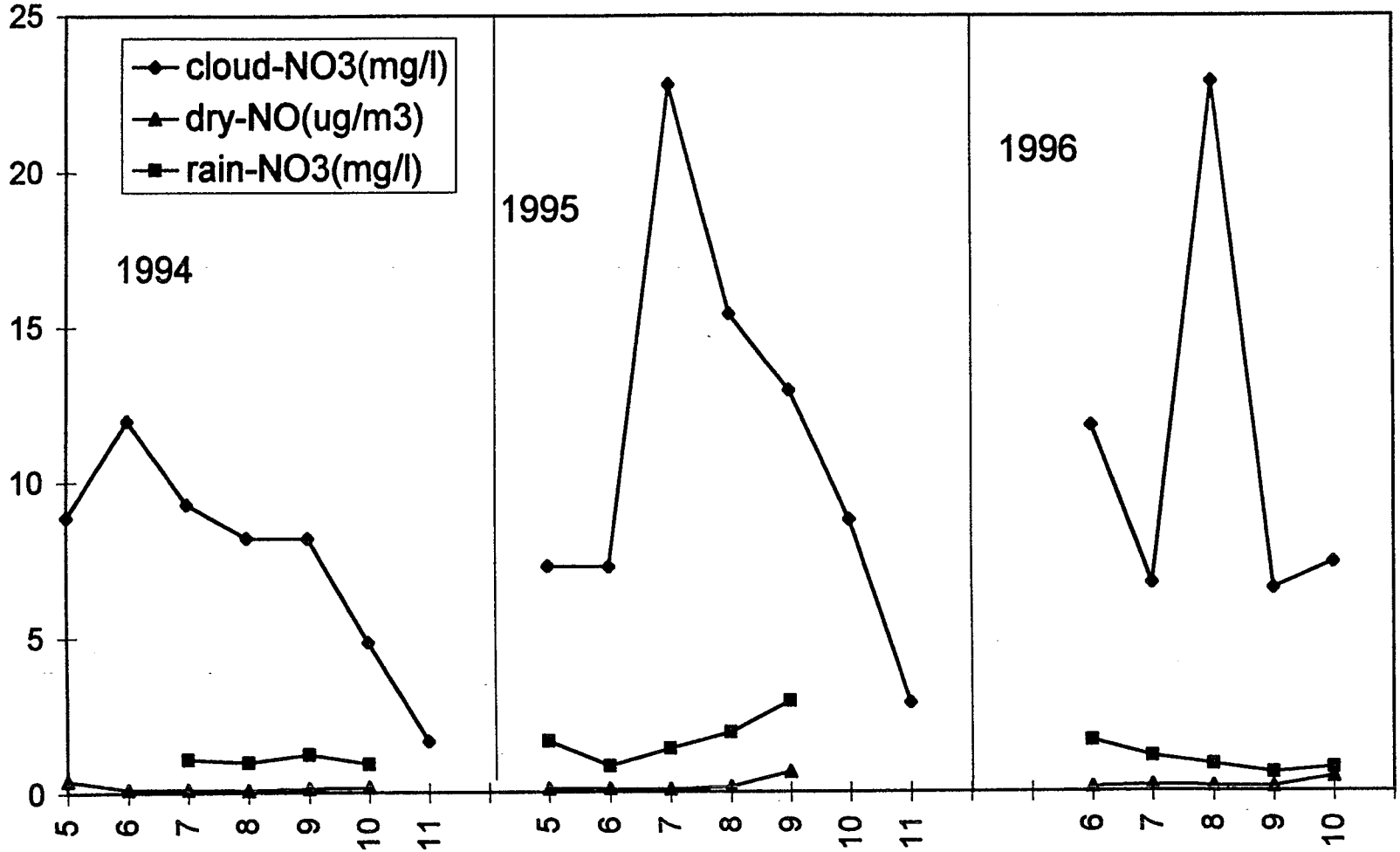


Figure 3-189. Mean monthly NO_3^- concentrations ($\mu g/m^3$) found in dry air and in rainwater and cloudwater (mg/L) at Whitetop Mountain, VA, from 1994 to 1996

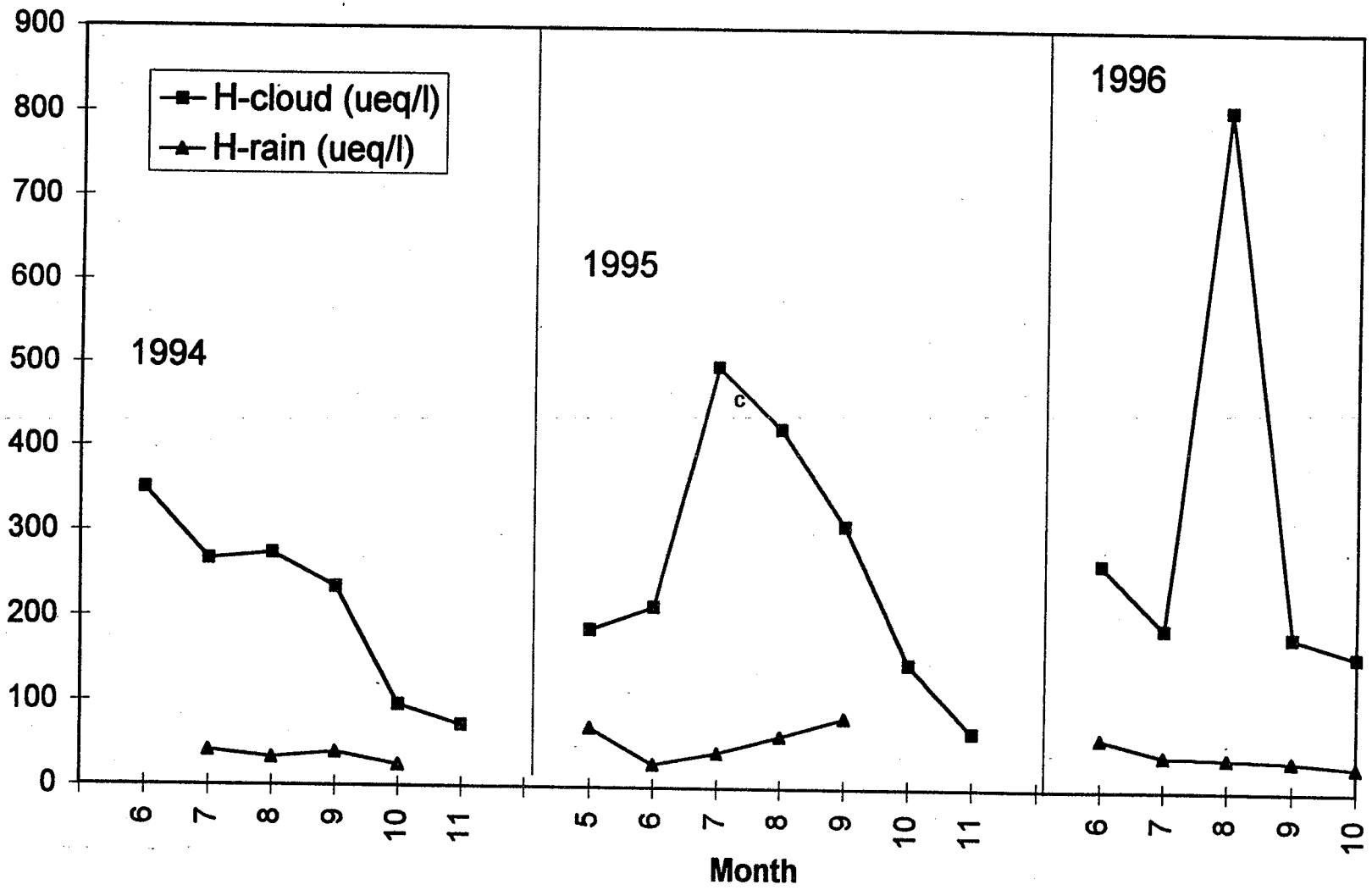


Figure 3-190. Hydrogen ion concentrations in rain and cloudwater (μeq/L) at Whitetop Mountain, VA, from 1994 to 1996

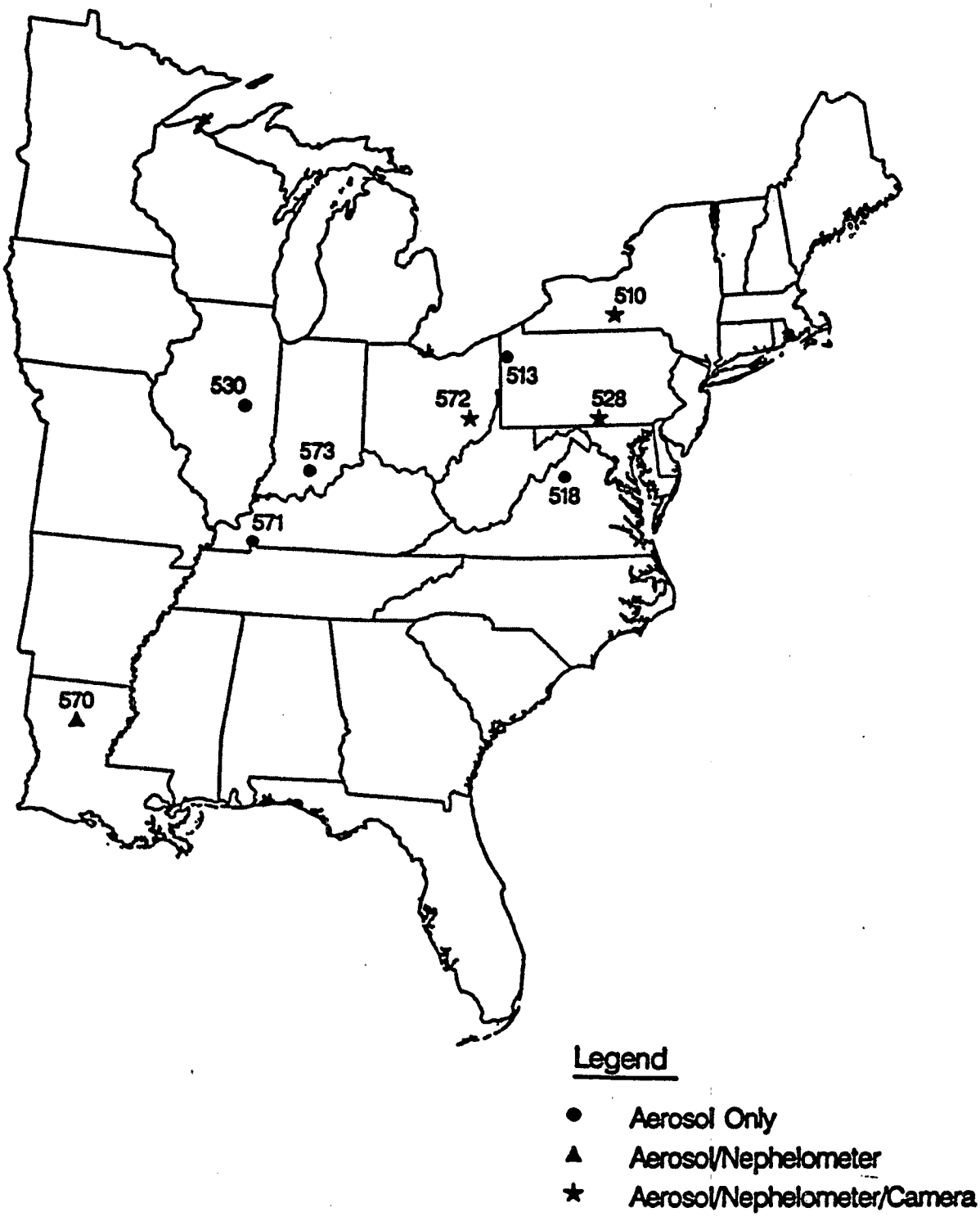


Figure 3-191. Locations of visibility monitoring sites

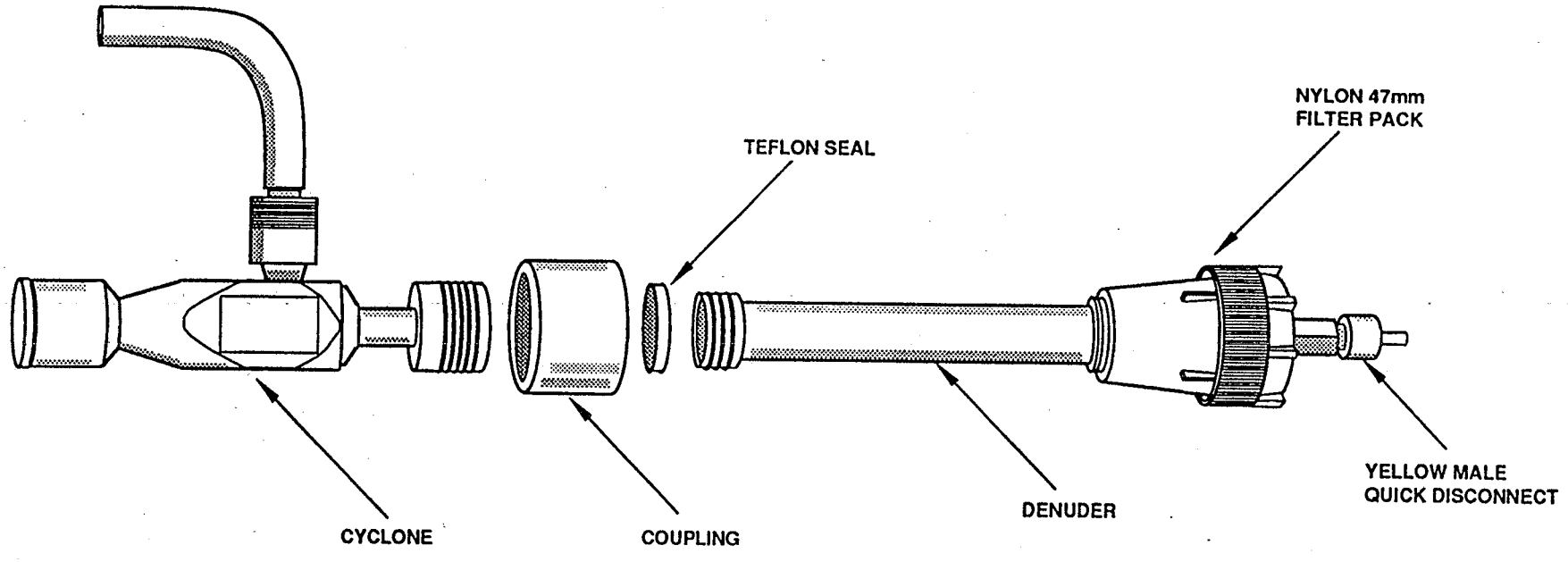


Figure 3-192. Diagram of the denuder assembly

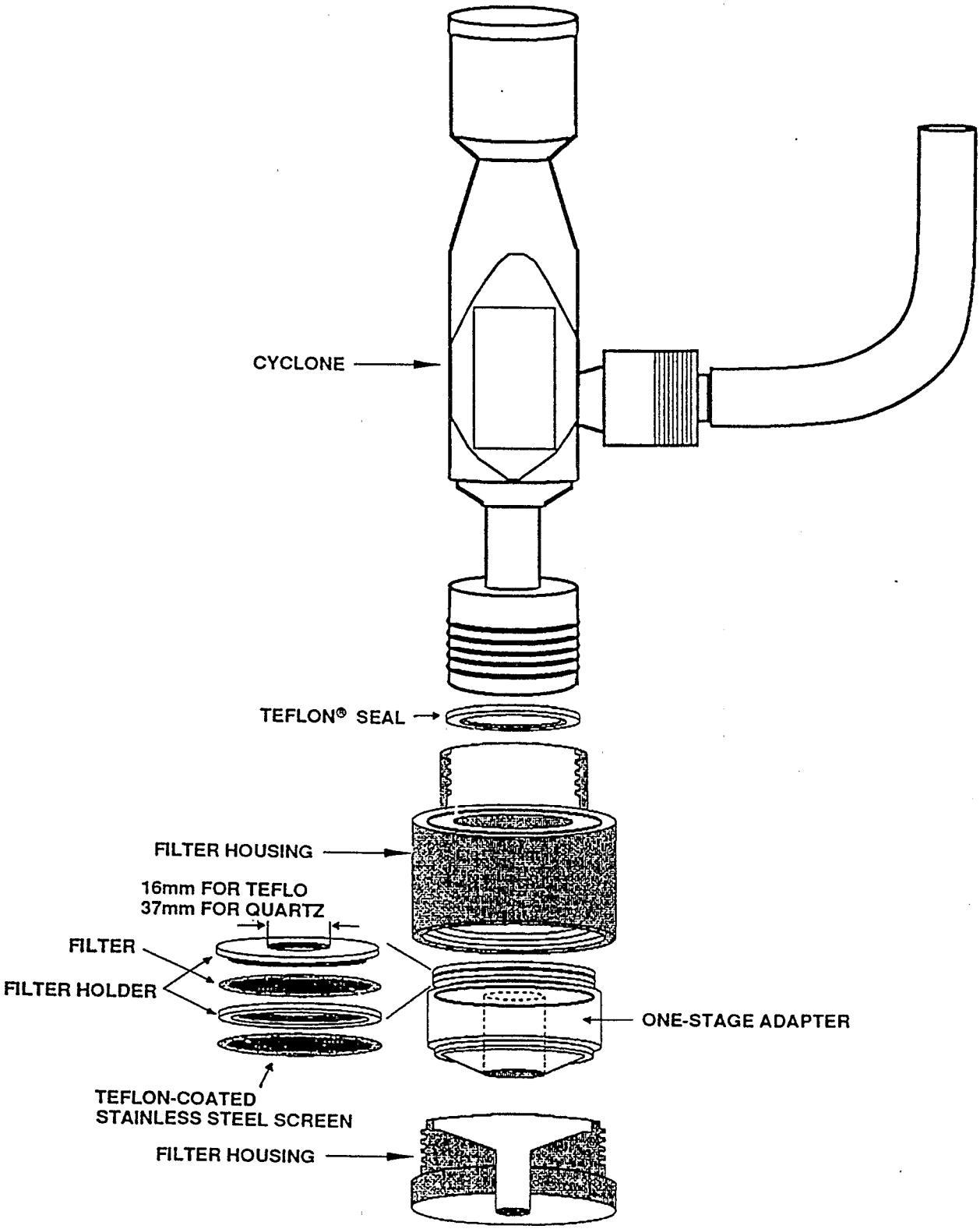


Figure 3-193. Teflo® and quartz assembly

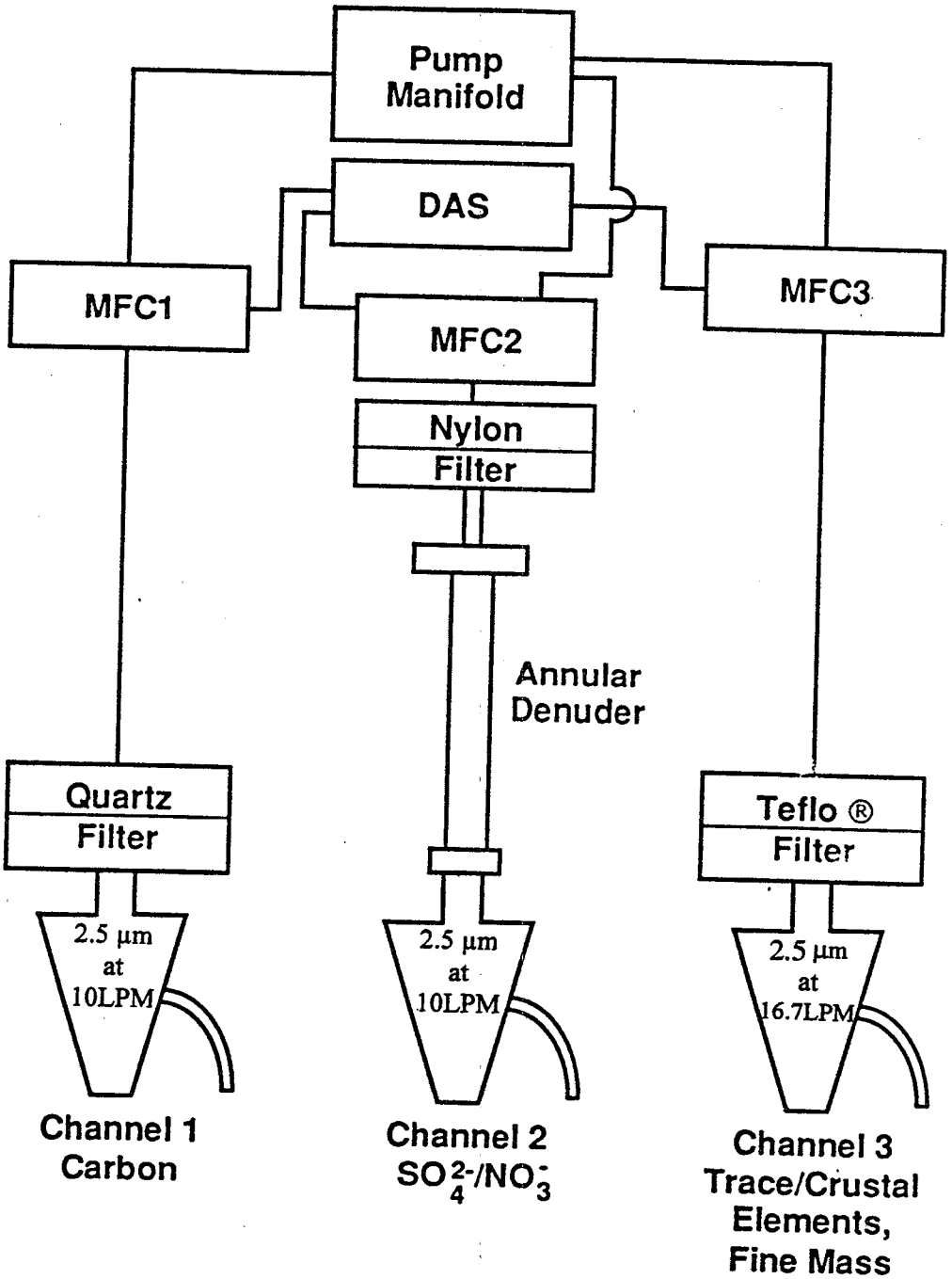


Figure 3-194. Visibility network aerosol sampling system

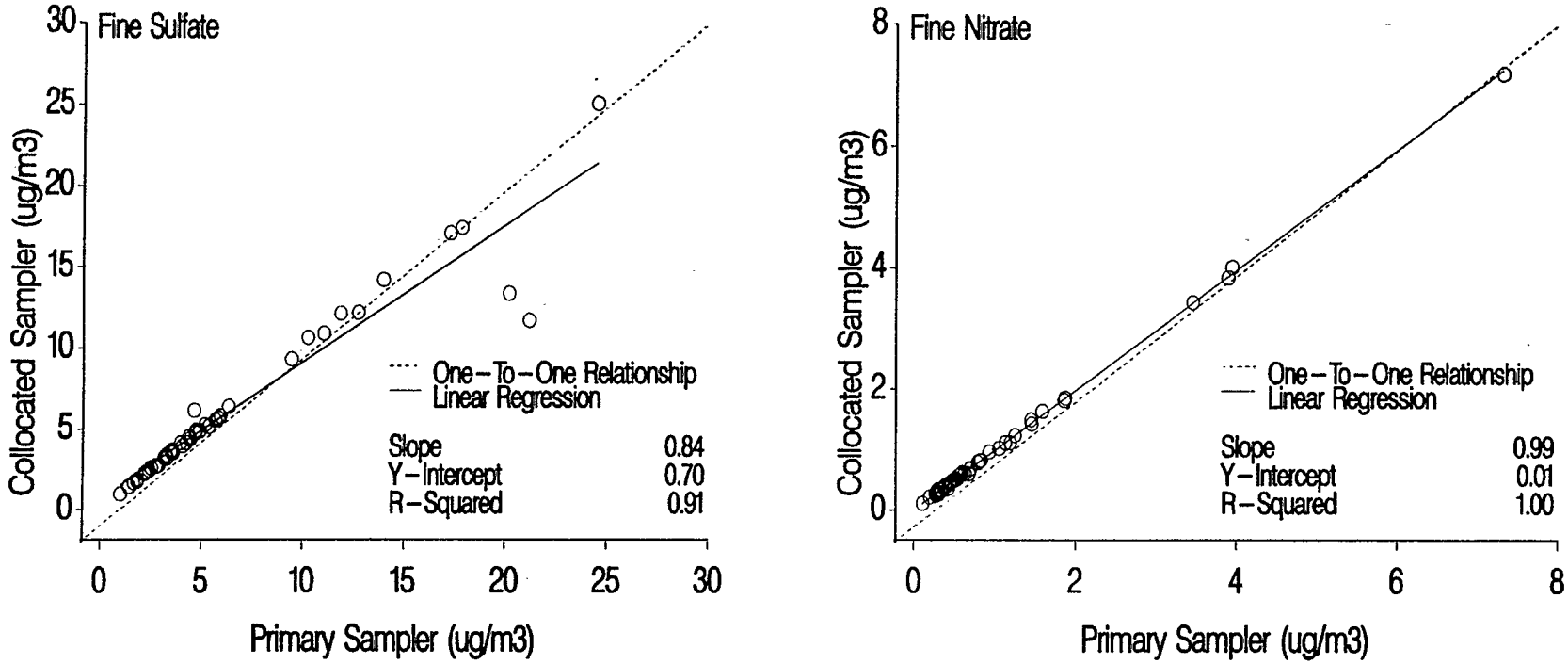
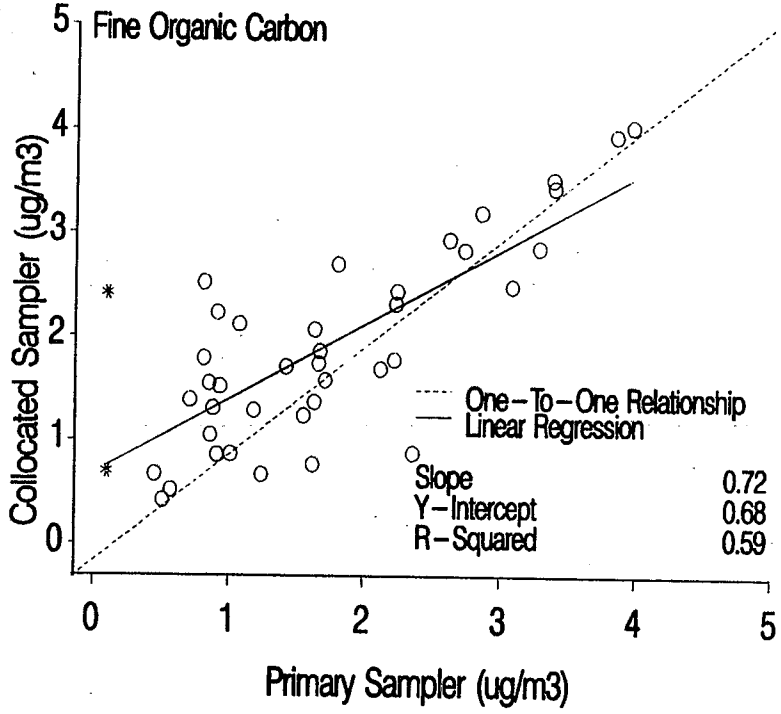


Figure 3-195. Linear regression plots for collocated sampling of SO_4^{2-} and NO_3^-



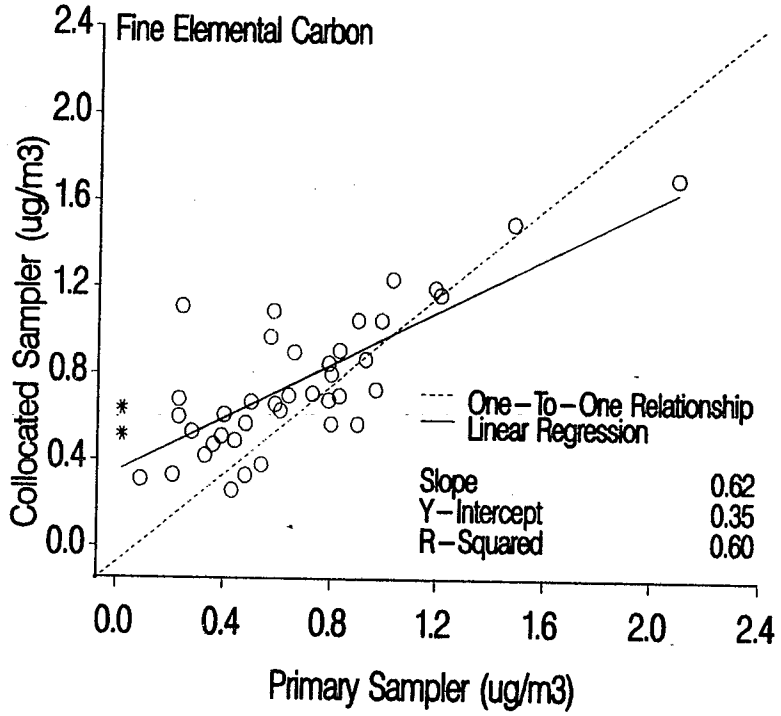


Figure 3-196. Linear regression plots for collocated sampling of fine organic carbon and fine elemental carbon

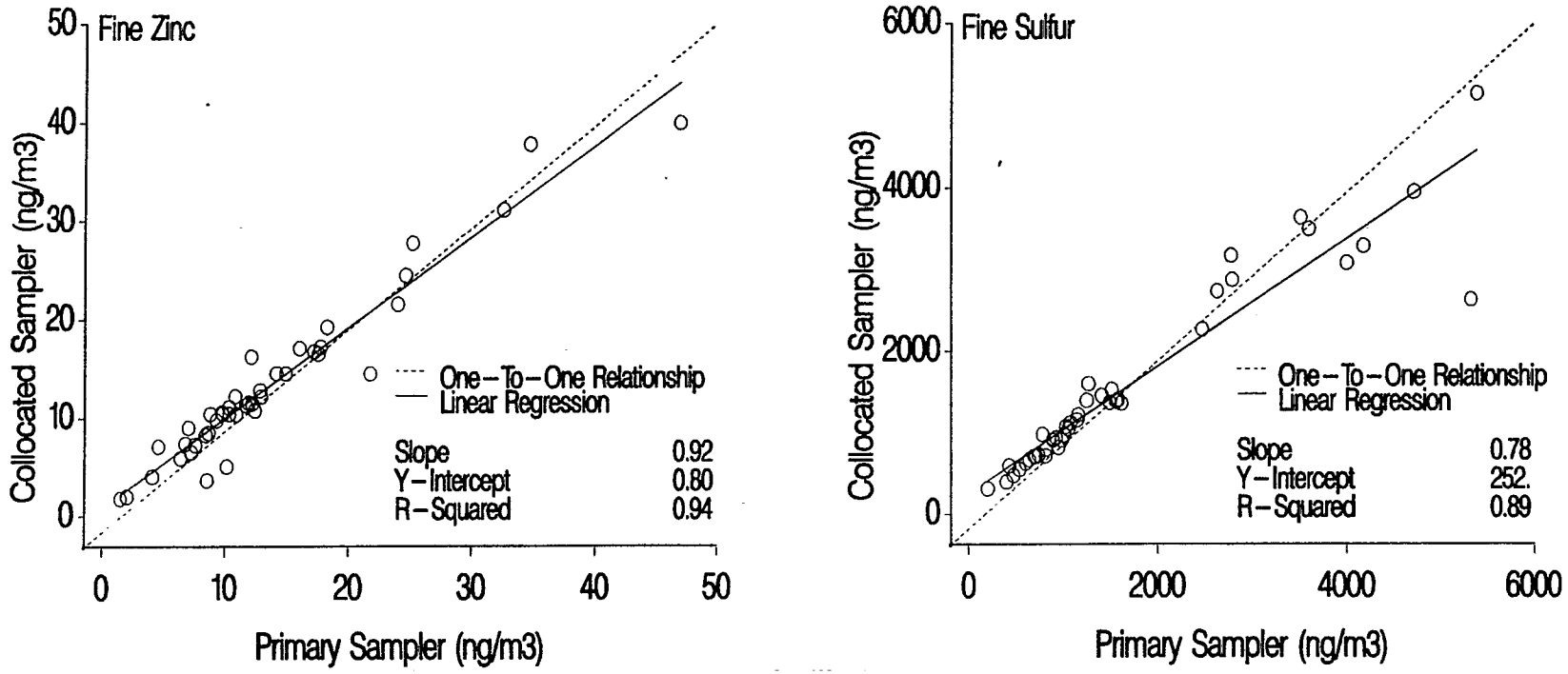


Figure 3-197. Linear regression plots for collocated sampling of fine zinc and fine sulfur

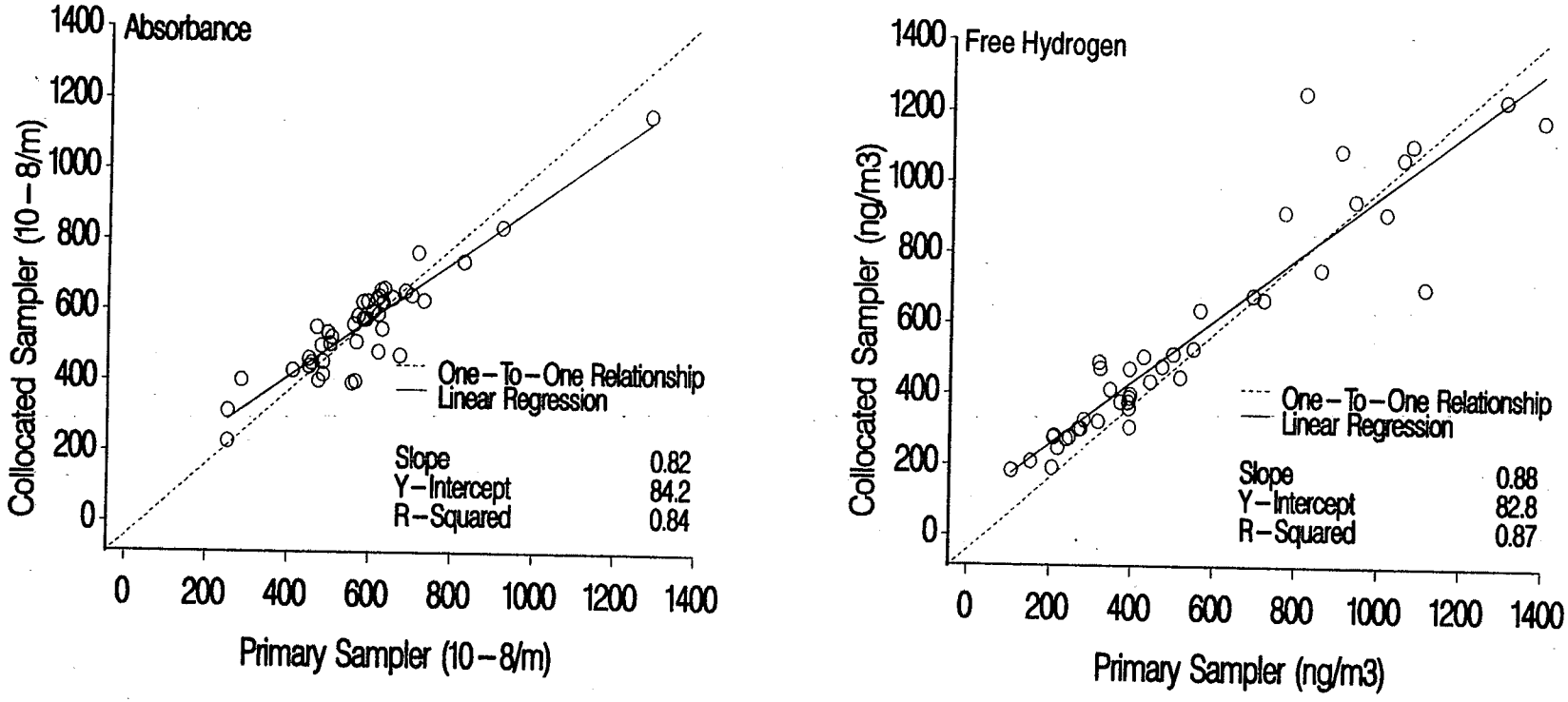


Figure 3-198. Linear regression plots for collocated sampling of absorbance and free hydrogen

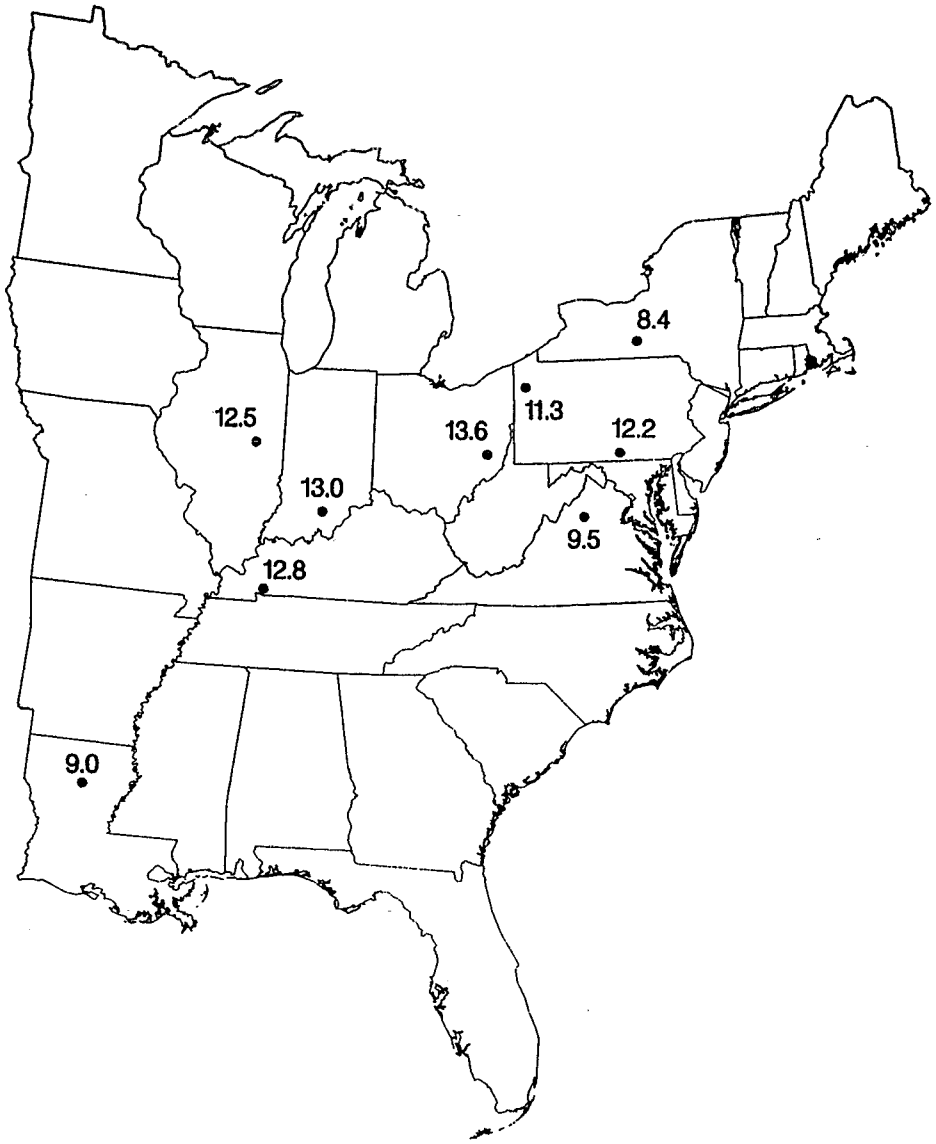


Figure 3-199. Annual average concentrations (<2.5 μm) of fine particles for 1994

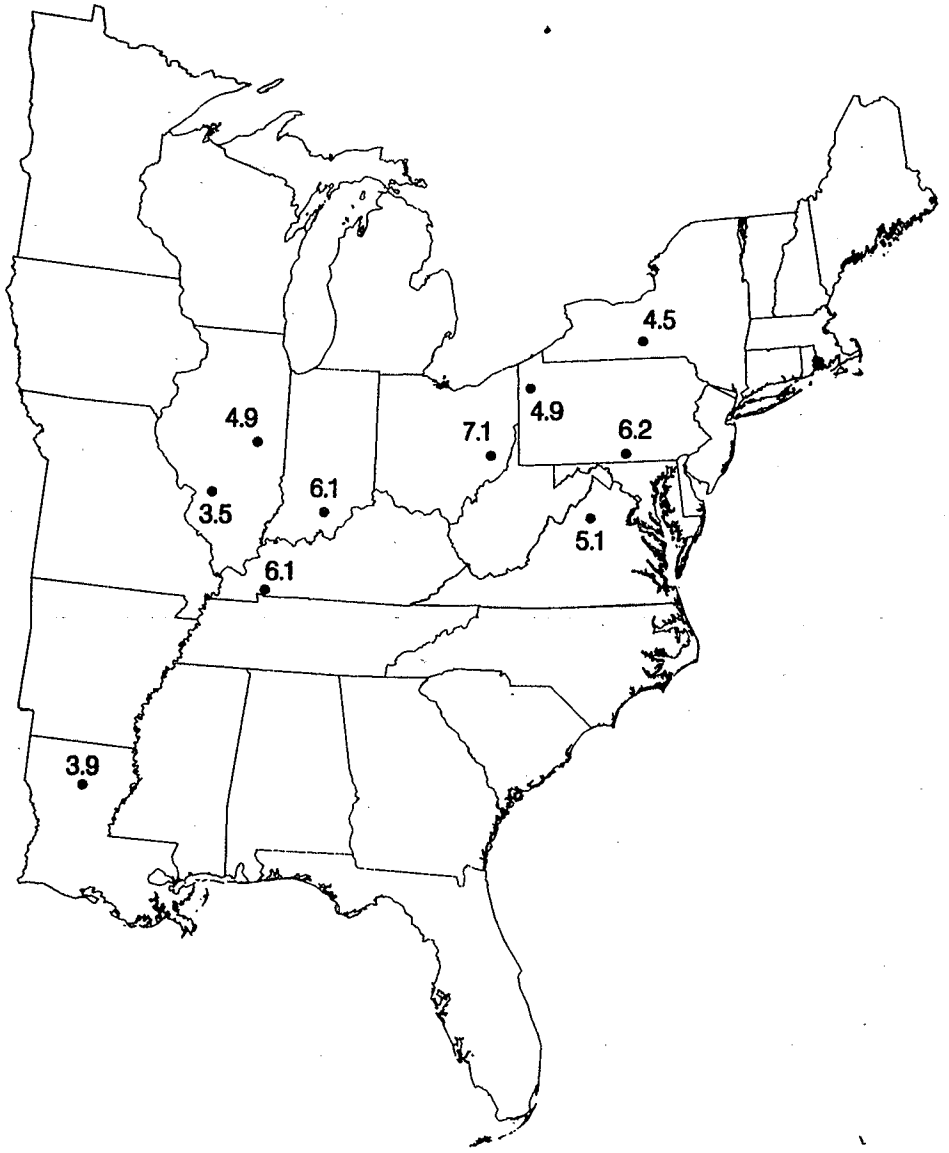


Figure 3-200. Annual average concentrations (<2.5 μm) of SO_4^{2-} for 1994

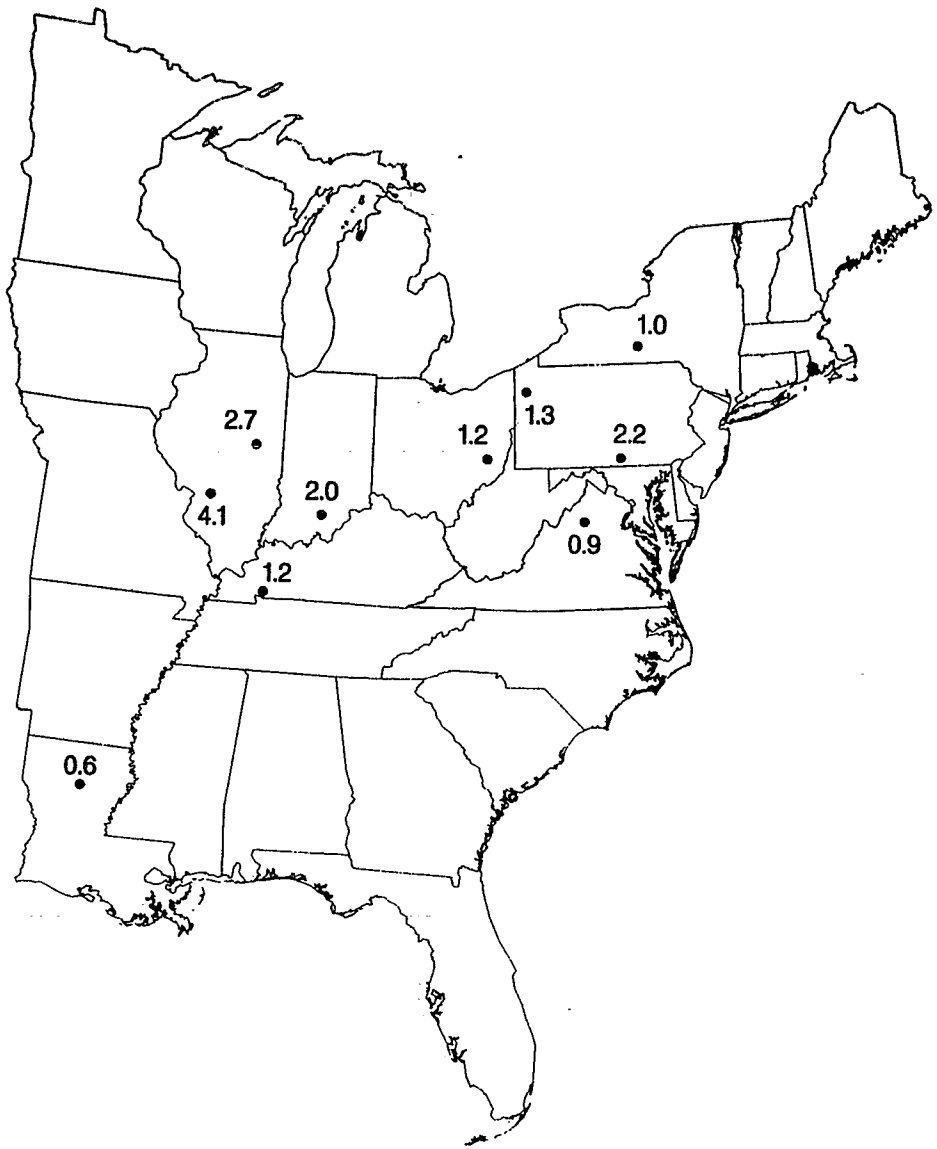


Figure 3-201. Annual average concentrations (<2.5 μm) of NO_3^- for 1994

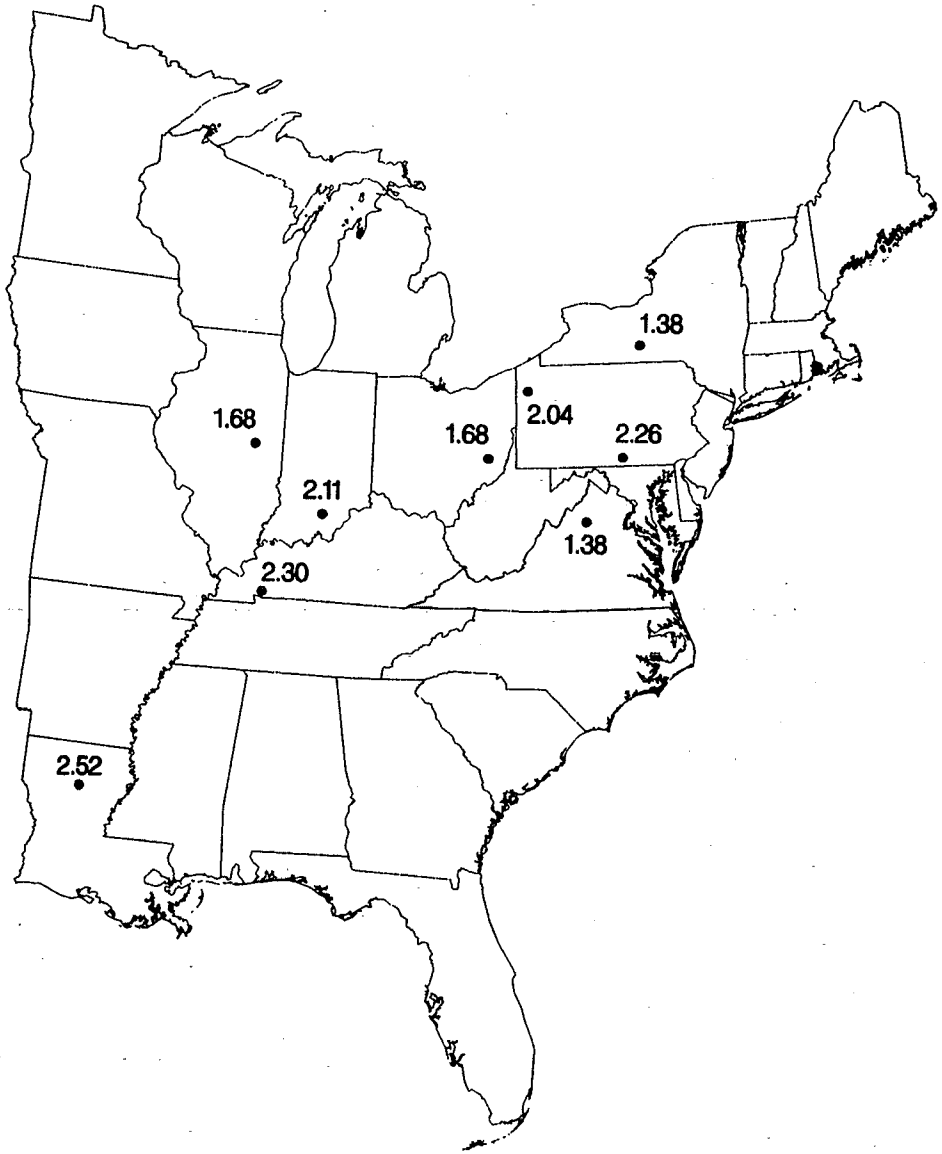


Figure 3-202. Annual average concentrations (<2.5 μm) of organic carbon for 1994

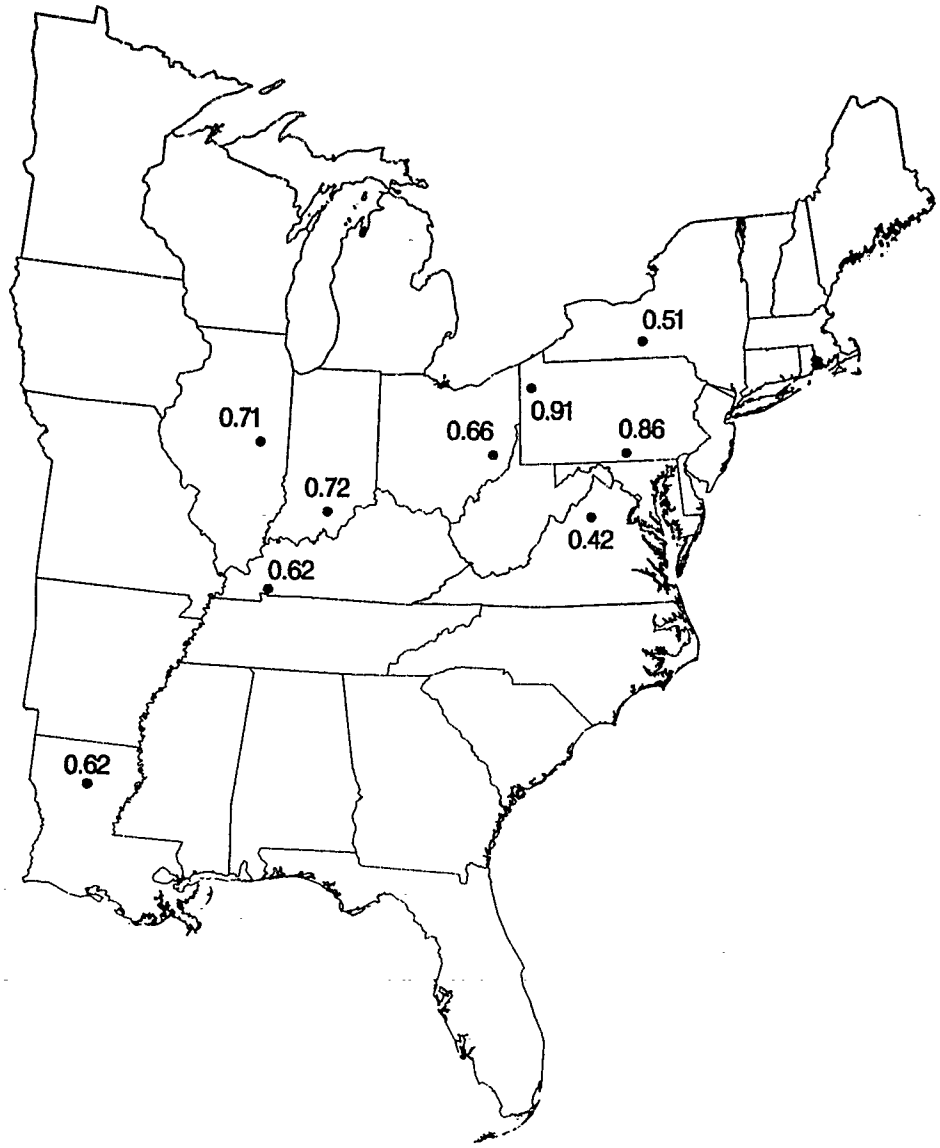


Figure 3-203. Annual average concentrations (<2.5 μm) of elemental carbon for 1994

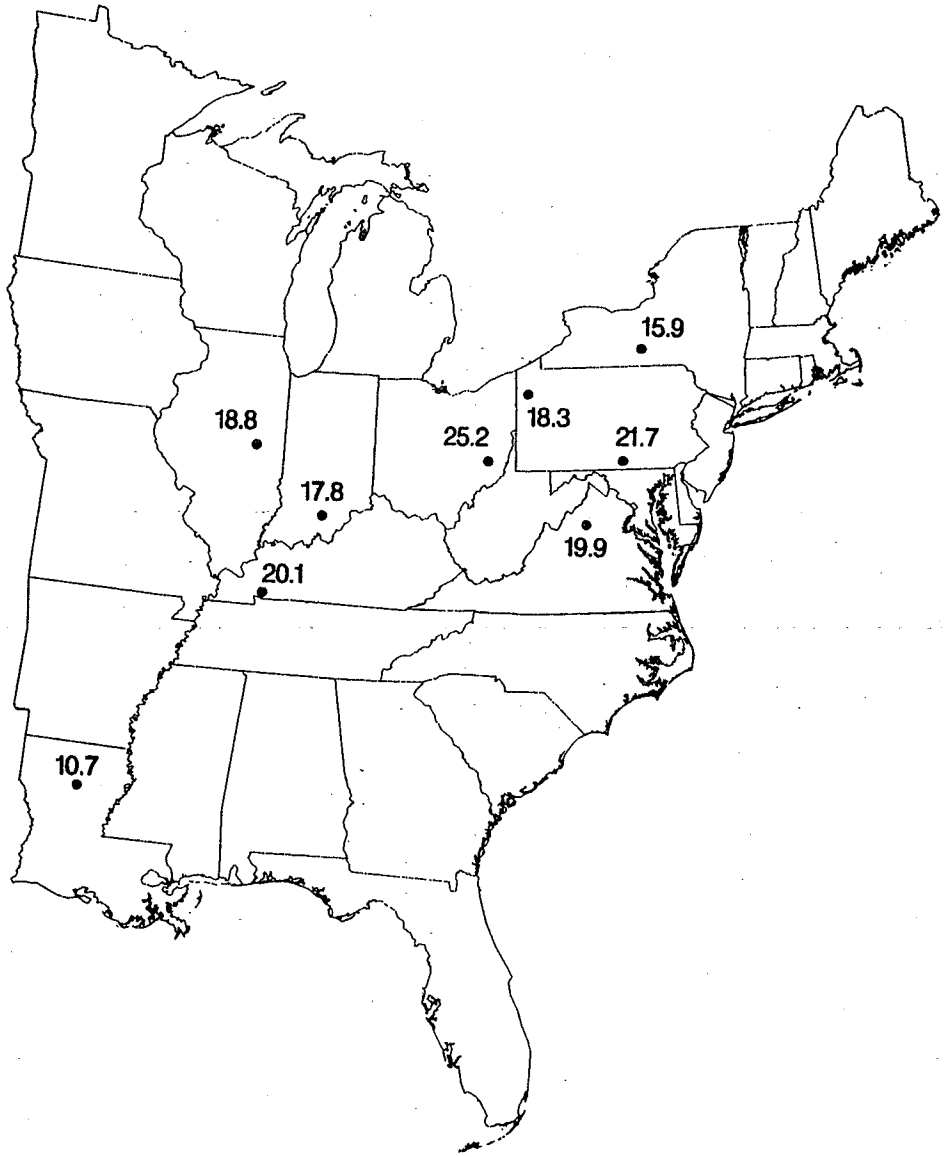


Figure 3-204. Summer average concentrations of fine particles for 1994

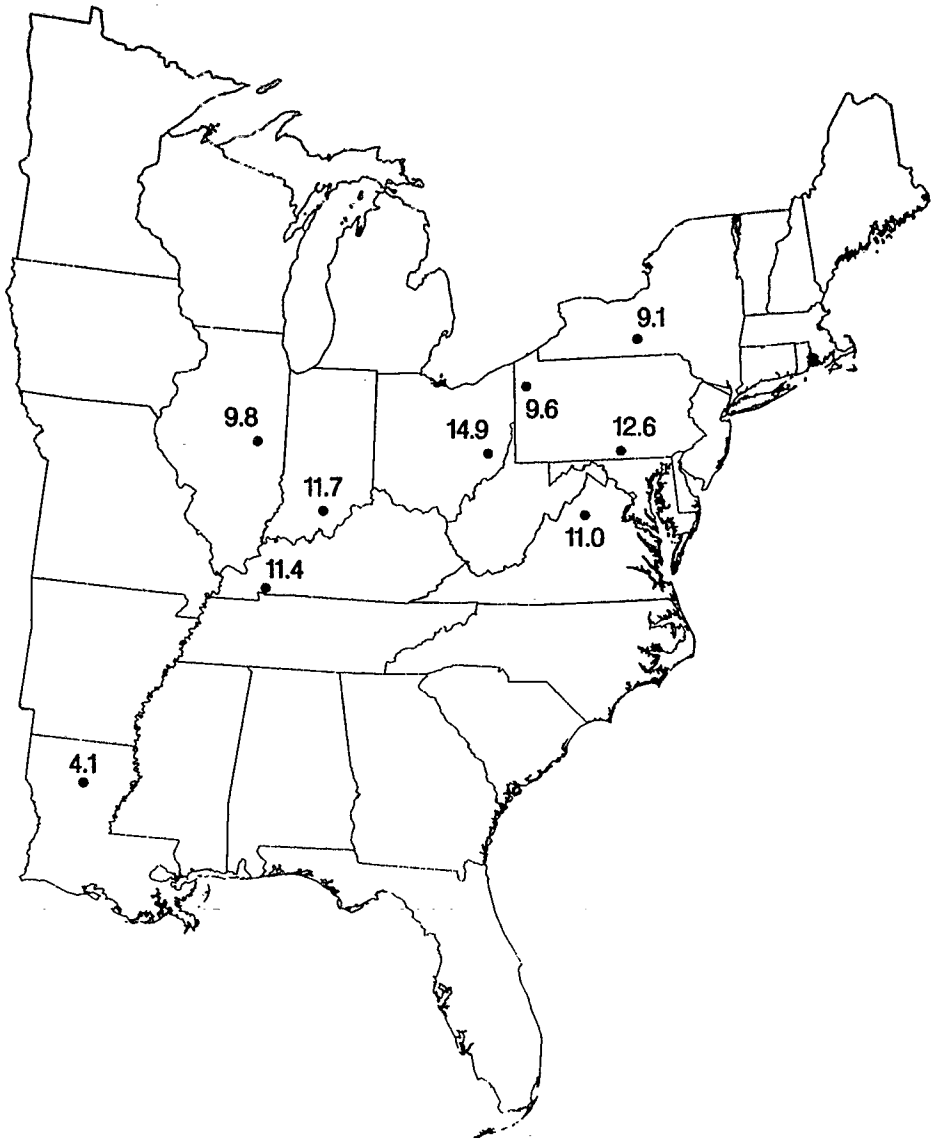


Figure 3-205. Summer average concentrations of SO_4^{2-} for 1994

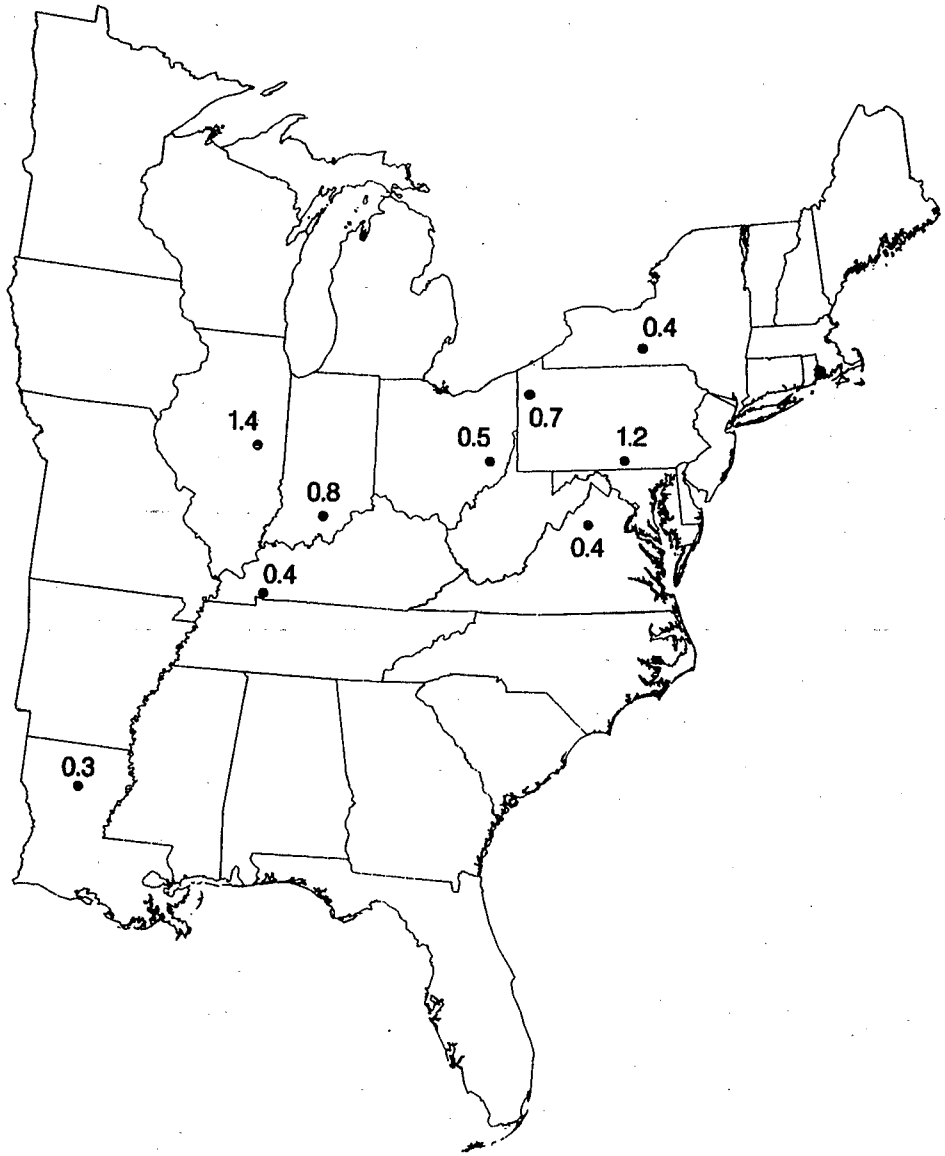


Figure 3-206. Summer average concentrations of NO_3^- for 1994

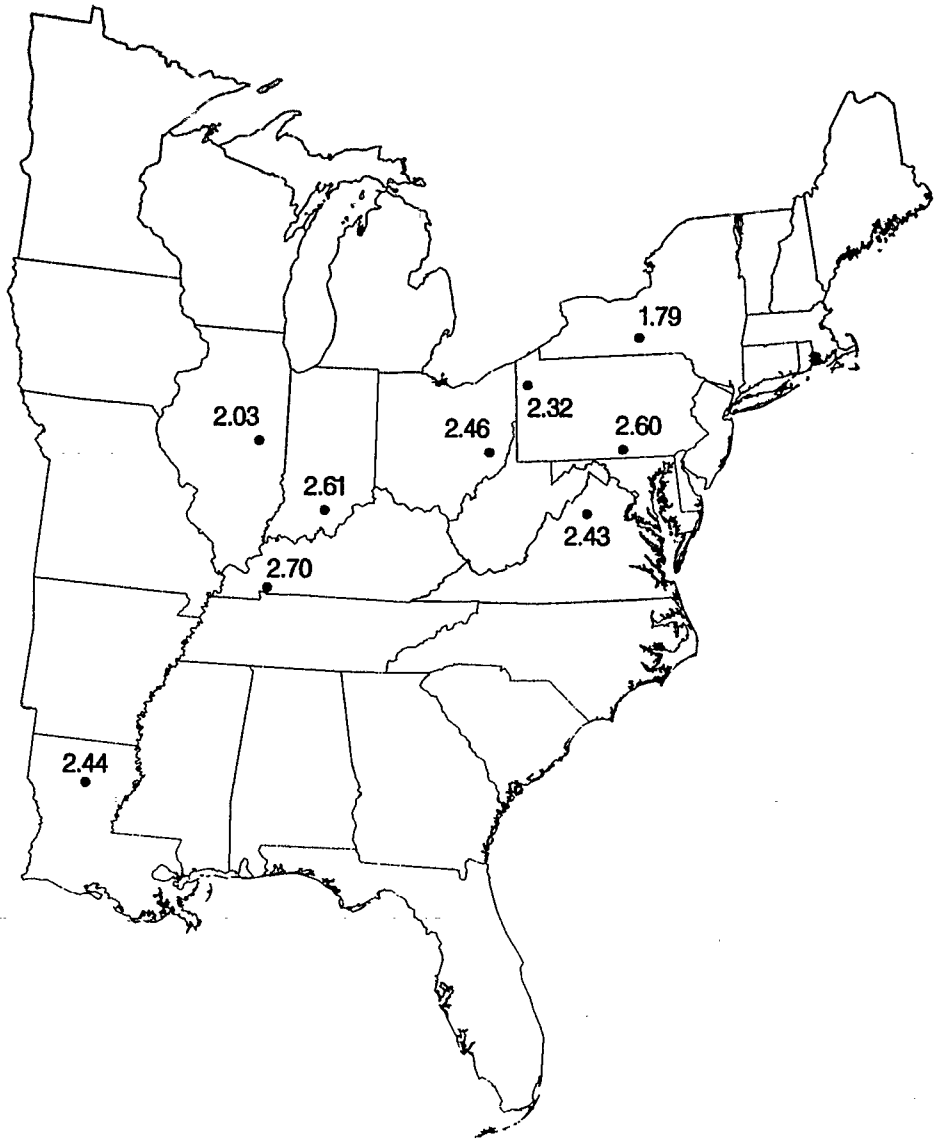


Figure 3-207. Summer average concentrations of organic carbon for 1994

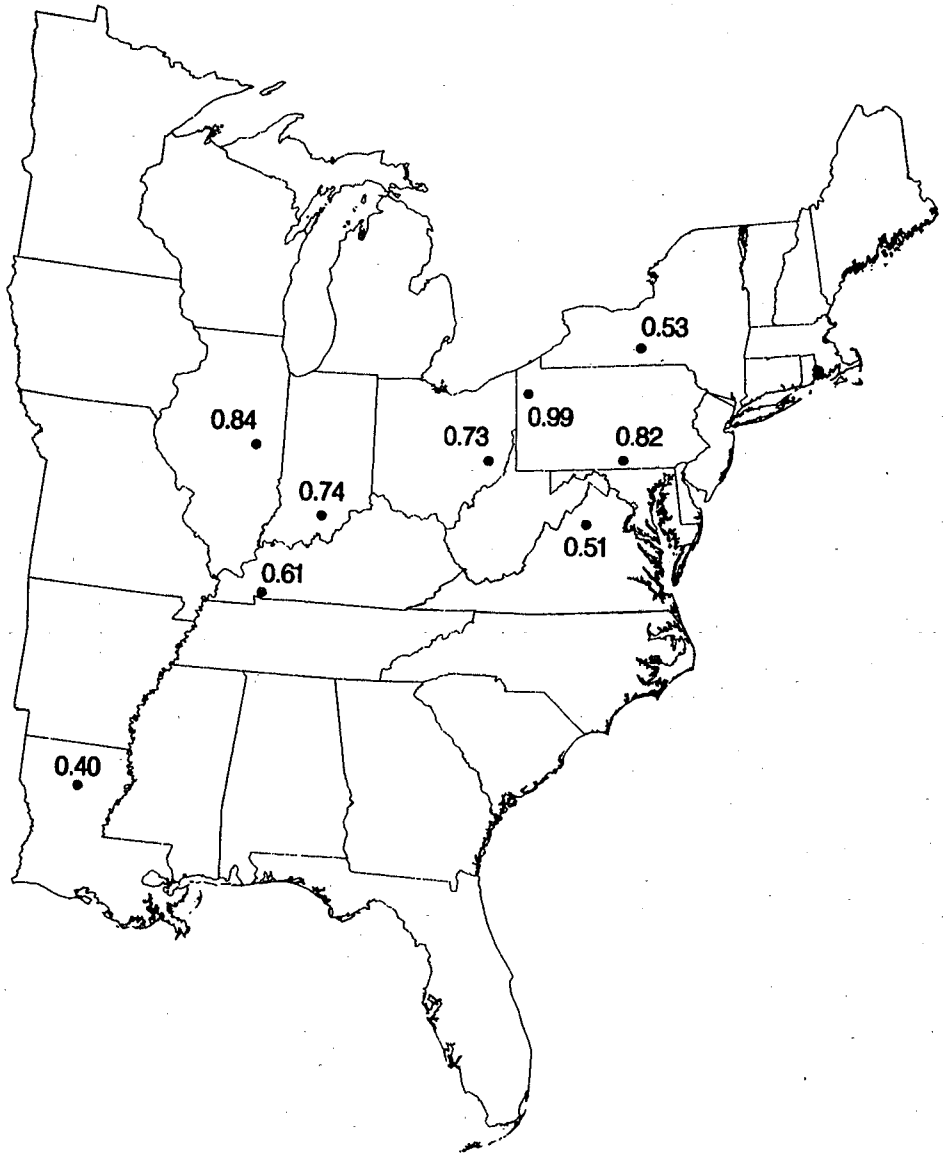


Figure 3-208. Summer average concentrations of elemental carbon for 1994

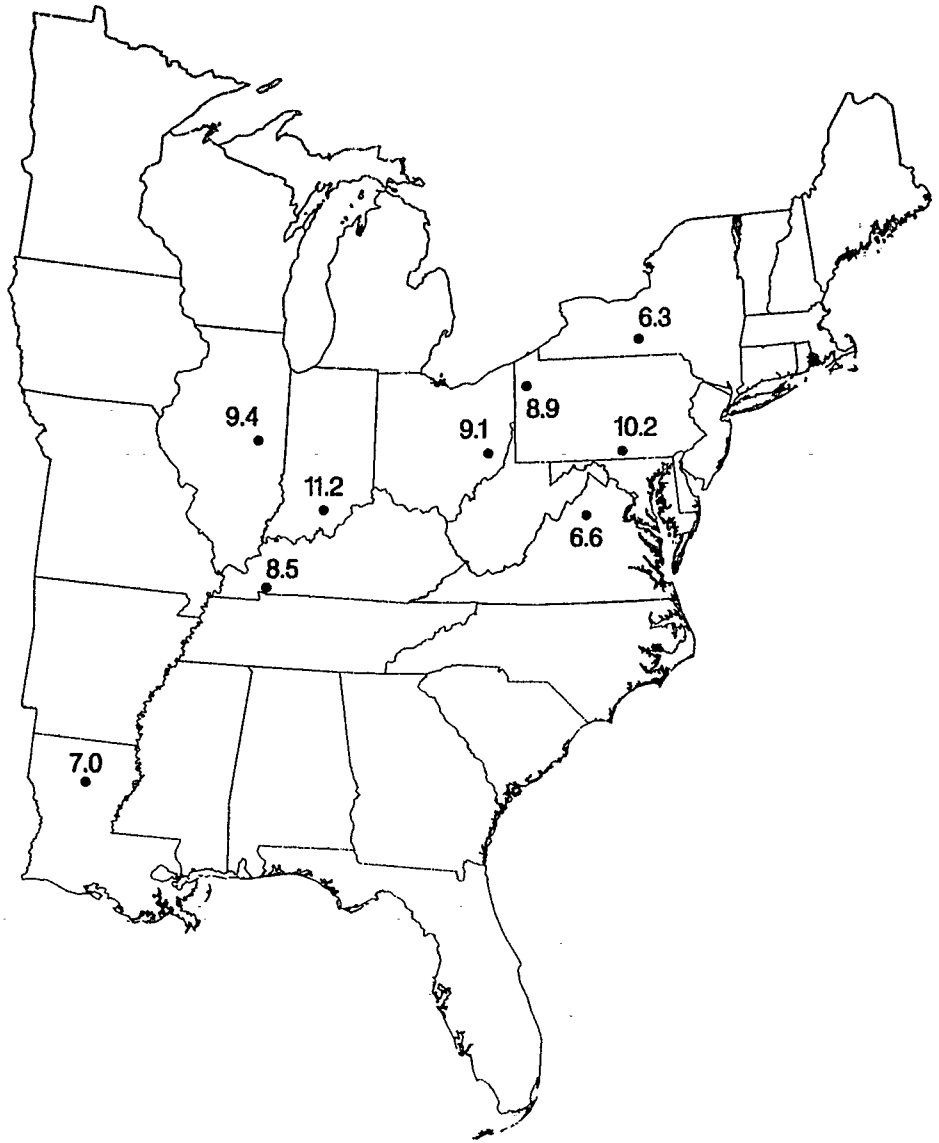


Figure 3-209. Winter average concentrations of fine particles for 1994

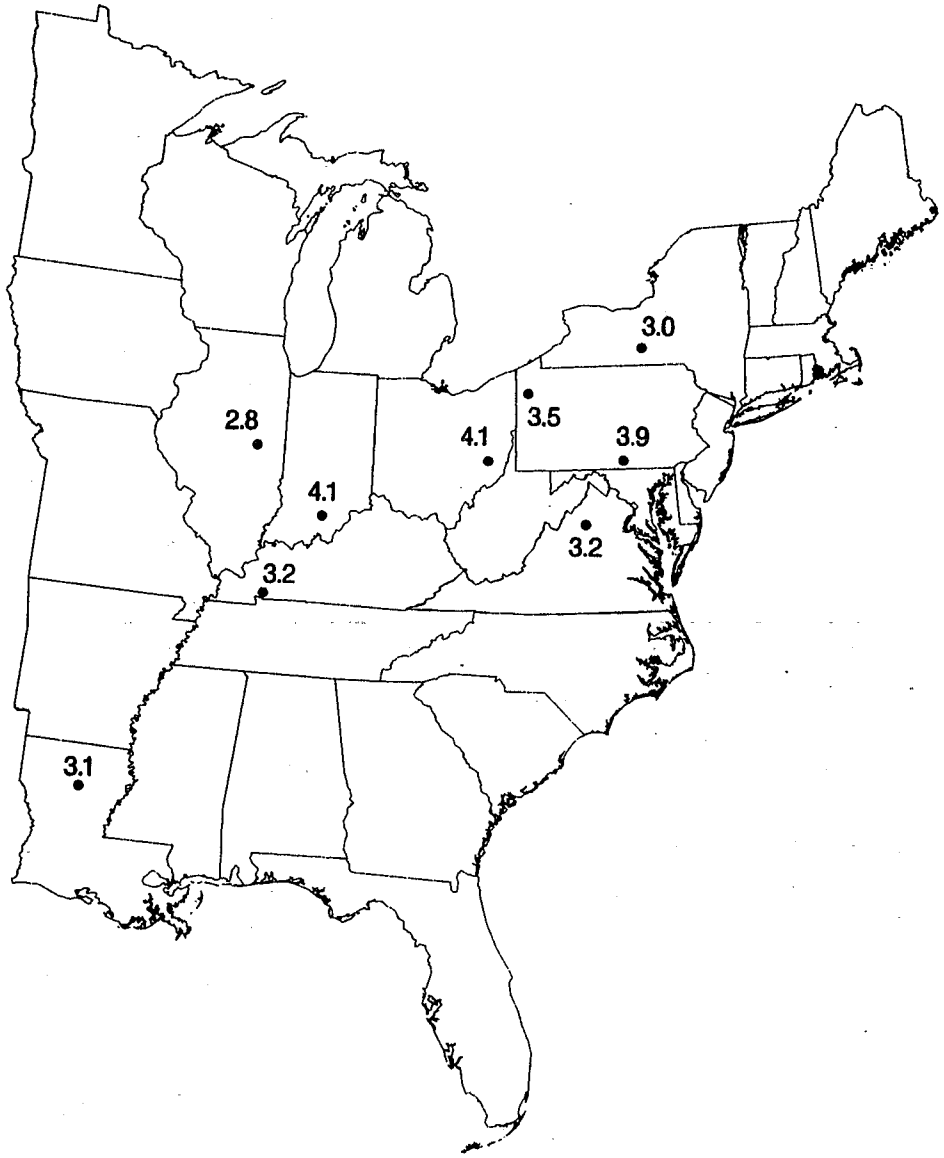


Figure 3-210. Winter average concentrations of SO_4^{2-} for 1994

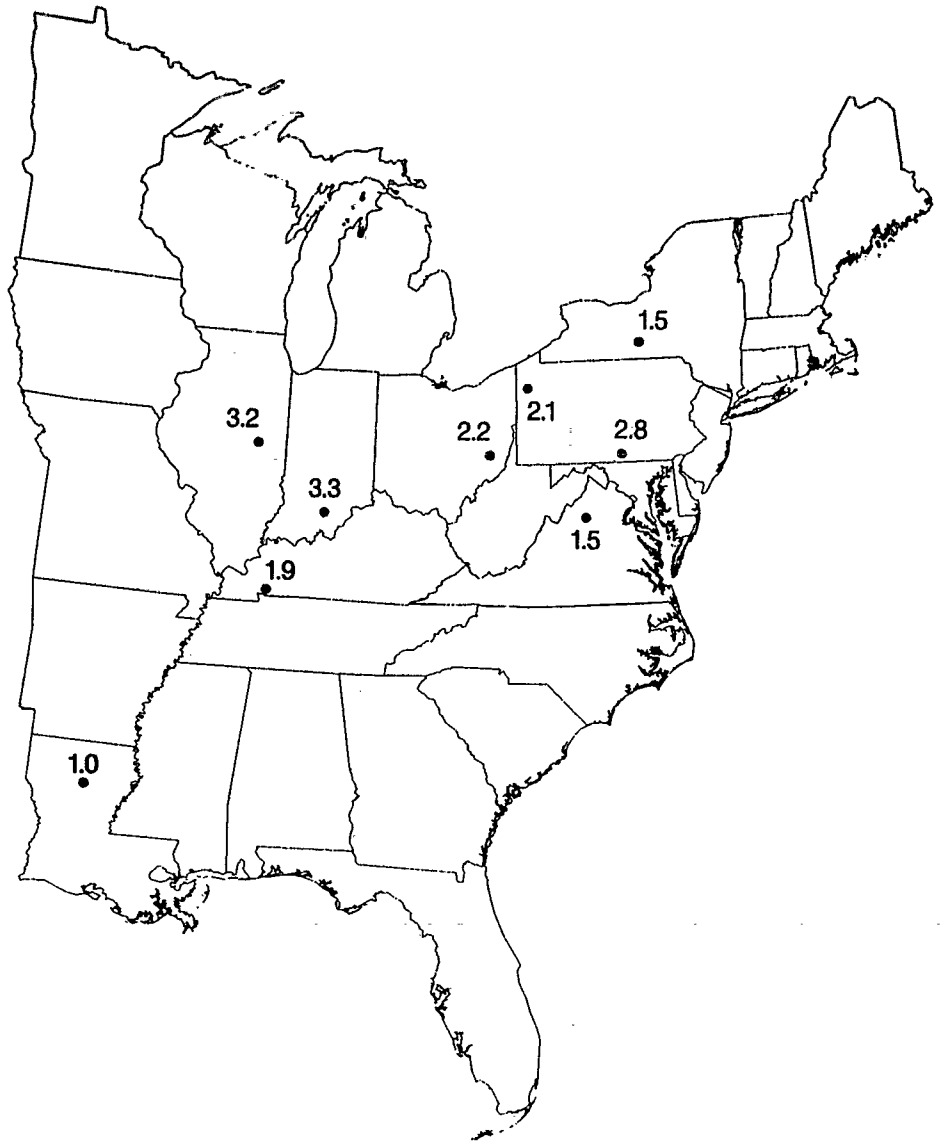


Figure 3-211. Winter average concentrations of NO_3^- for 1994

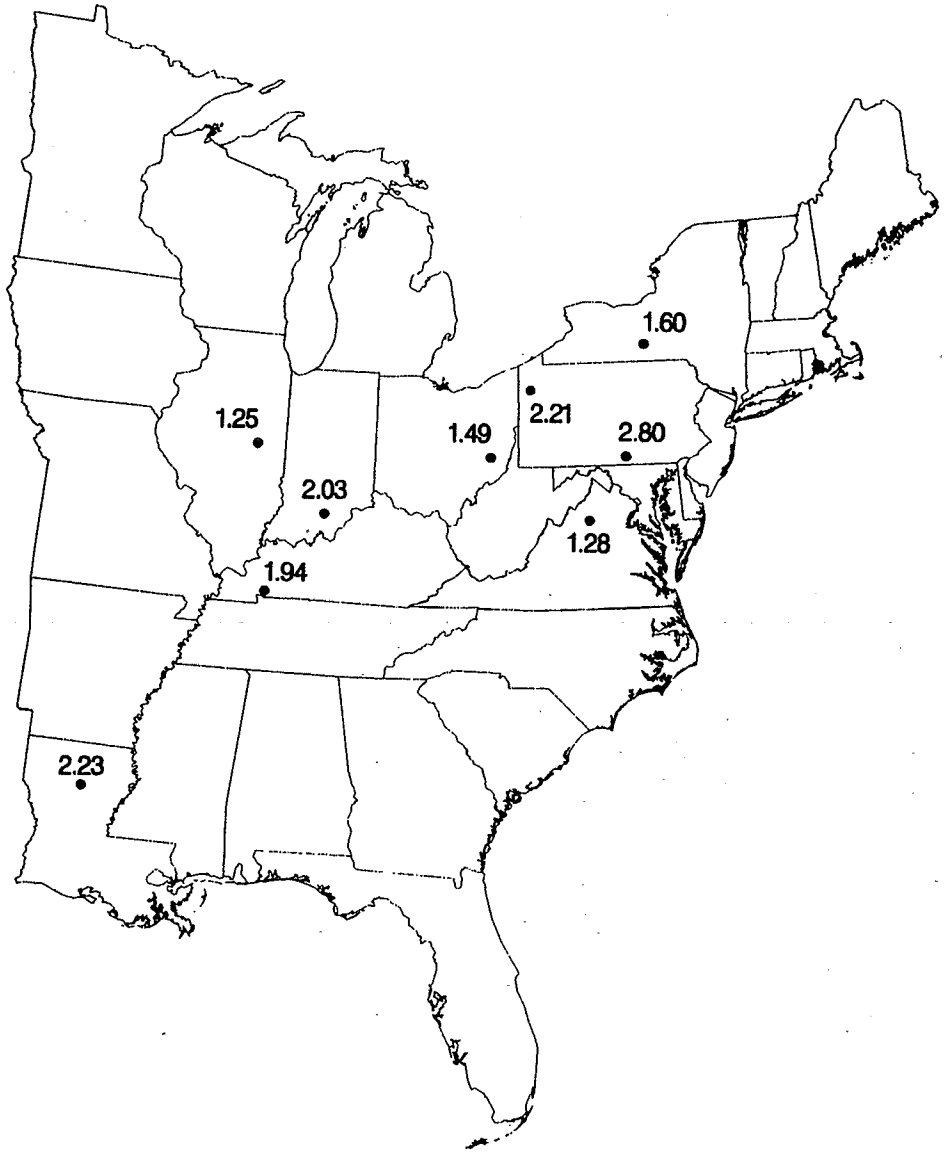


Figure 3-212. Winter average concentrations of organic carbon for 1994

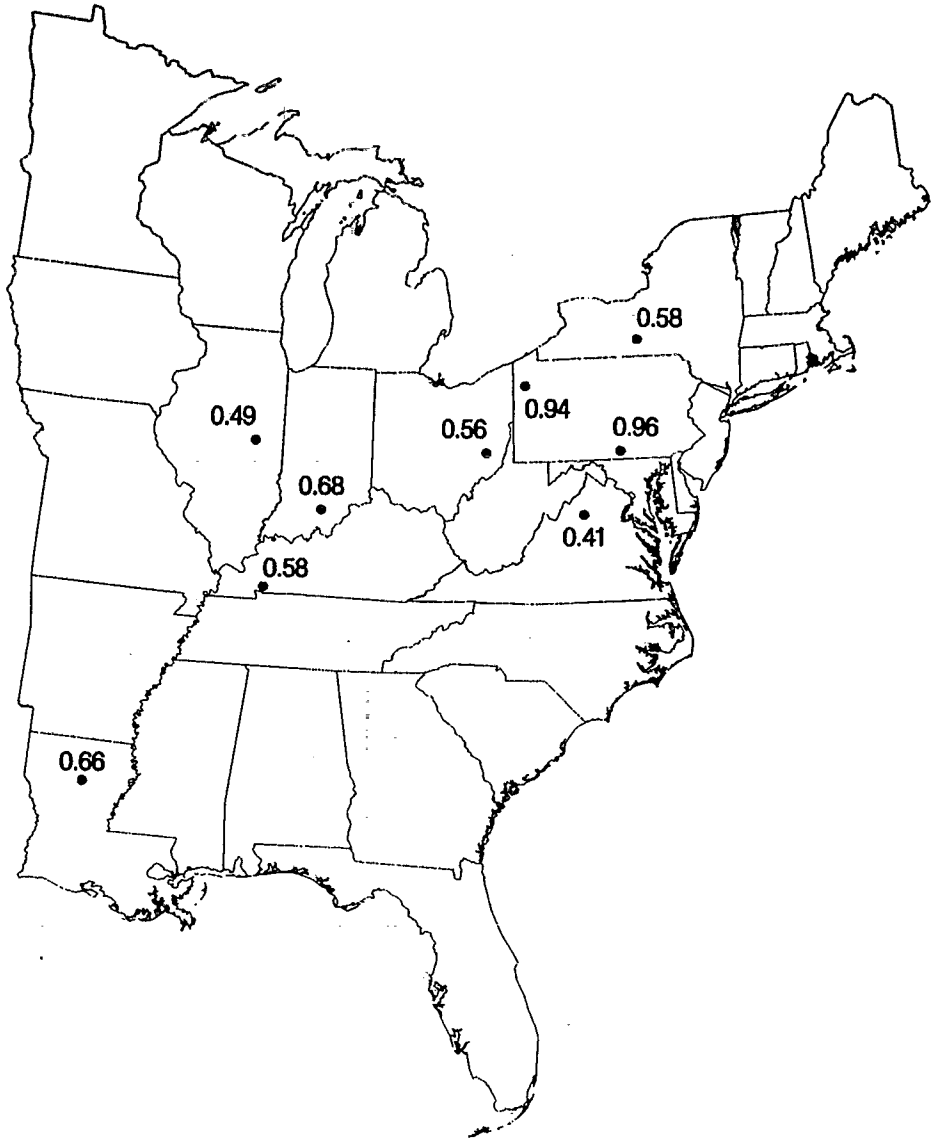


Figure 3-213. Winter average concentrations of elemental carbon for 1994

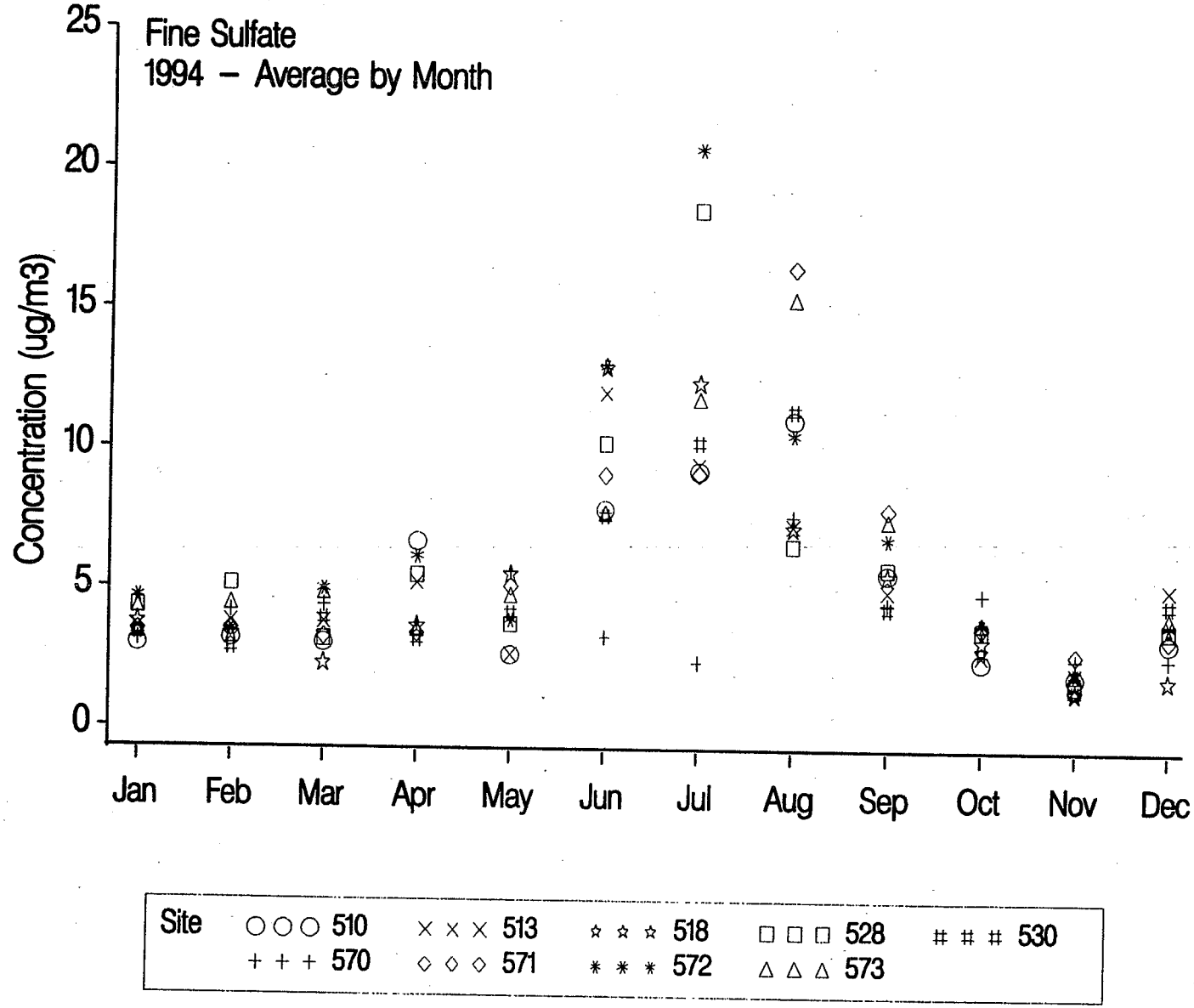


Figure 3-214. Time series plots of monthly average SO_4^{2-} concentrations for all sites in 1994

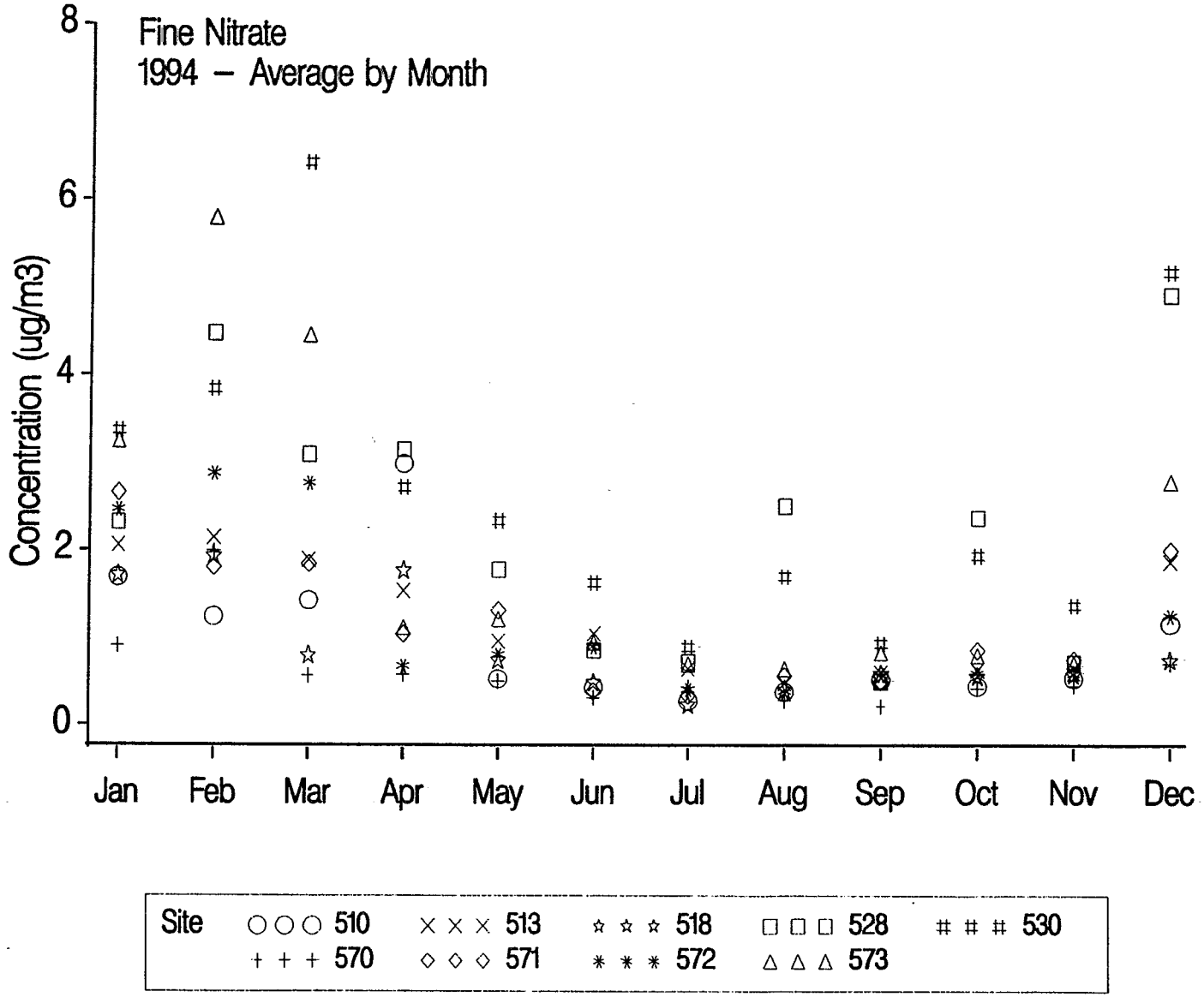


Figure 3-215. Time series plots of monthly average NO_3^- concentrations for all sites in 1994

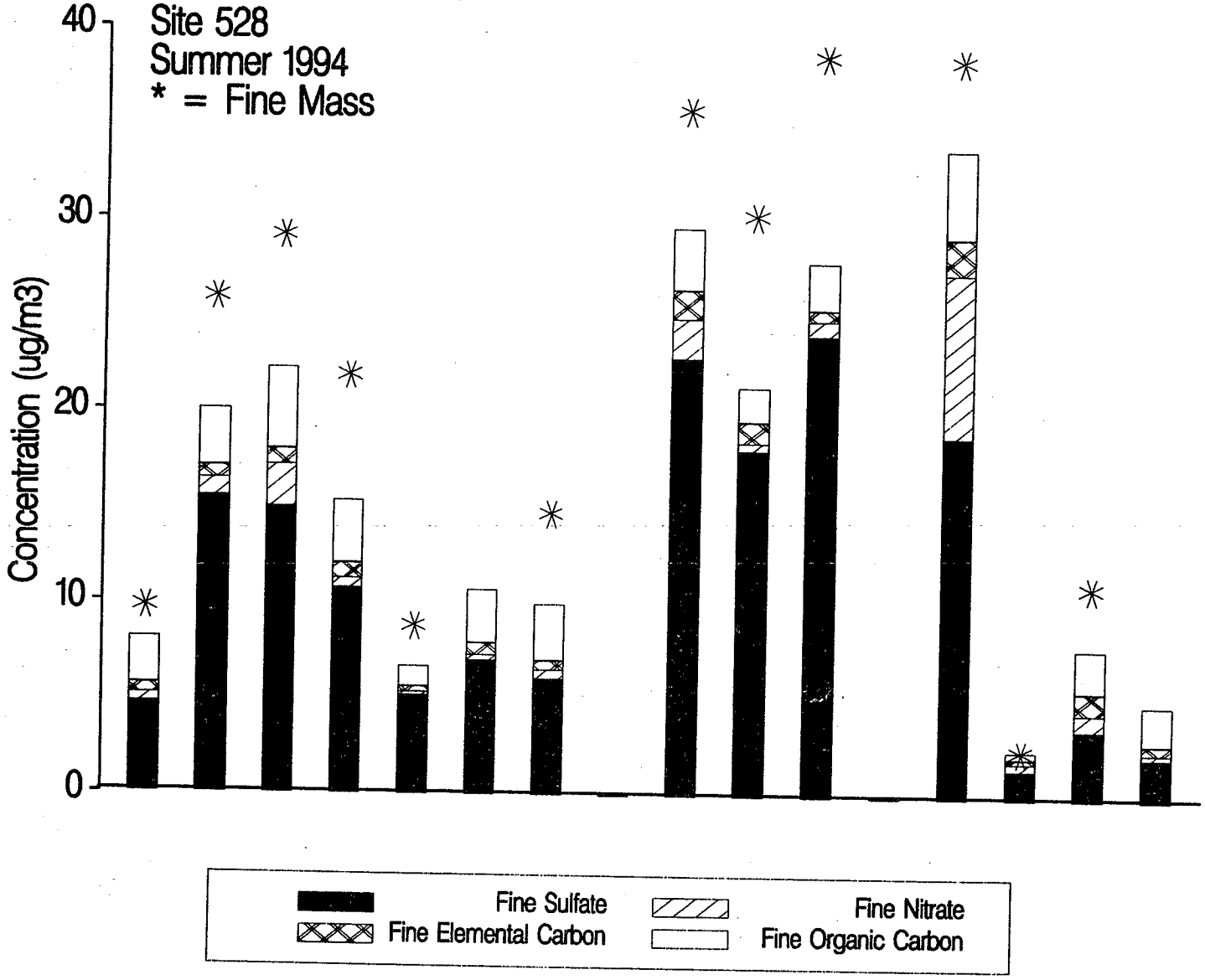


Figure 3-216. Time series bar charts of 24-hour concentrations of fine mass, SO_4^{2-}, NO_3^-, organics, and elemental carbon measured in the summer of 1994 for Site 528

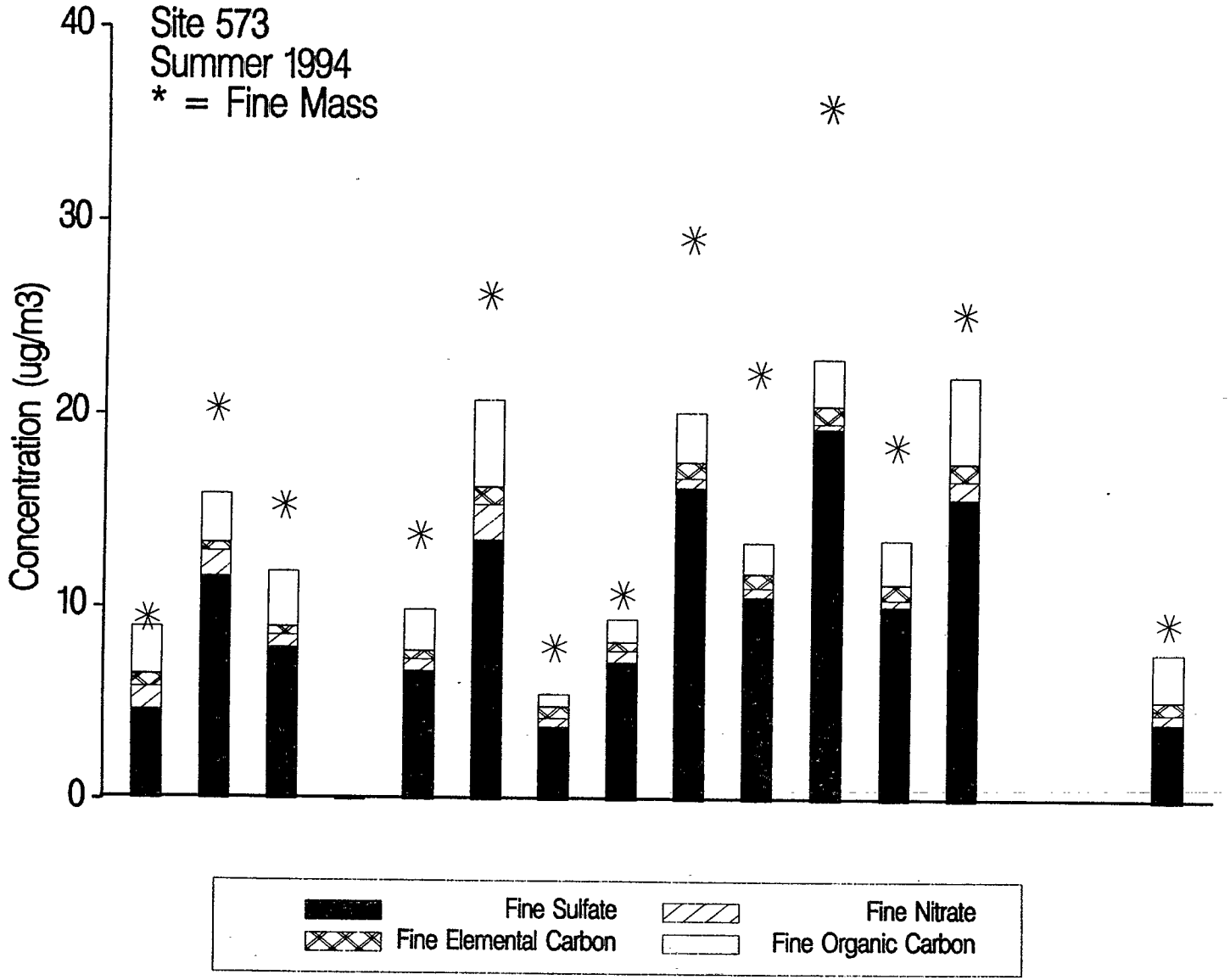


Figure 3-217. Time series bar charts of 24-hour concentrations of fine mass, SO_4^{2-}, NO_3^-, organics, and elemental carbon measured in the summer of 1994 for Site 573

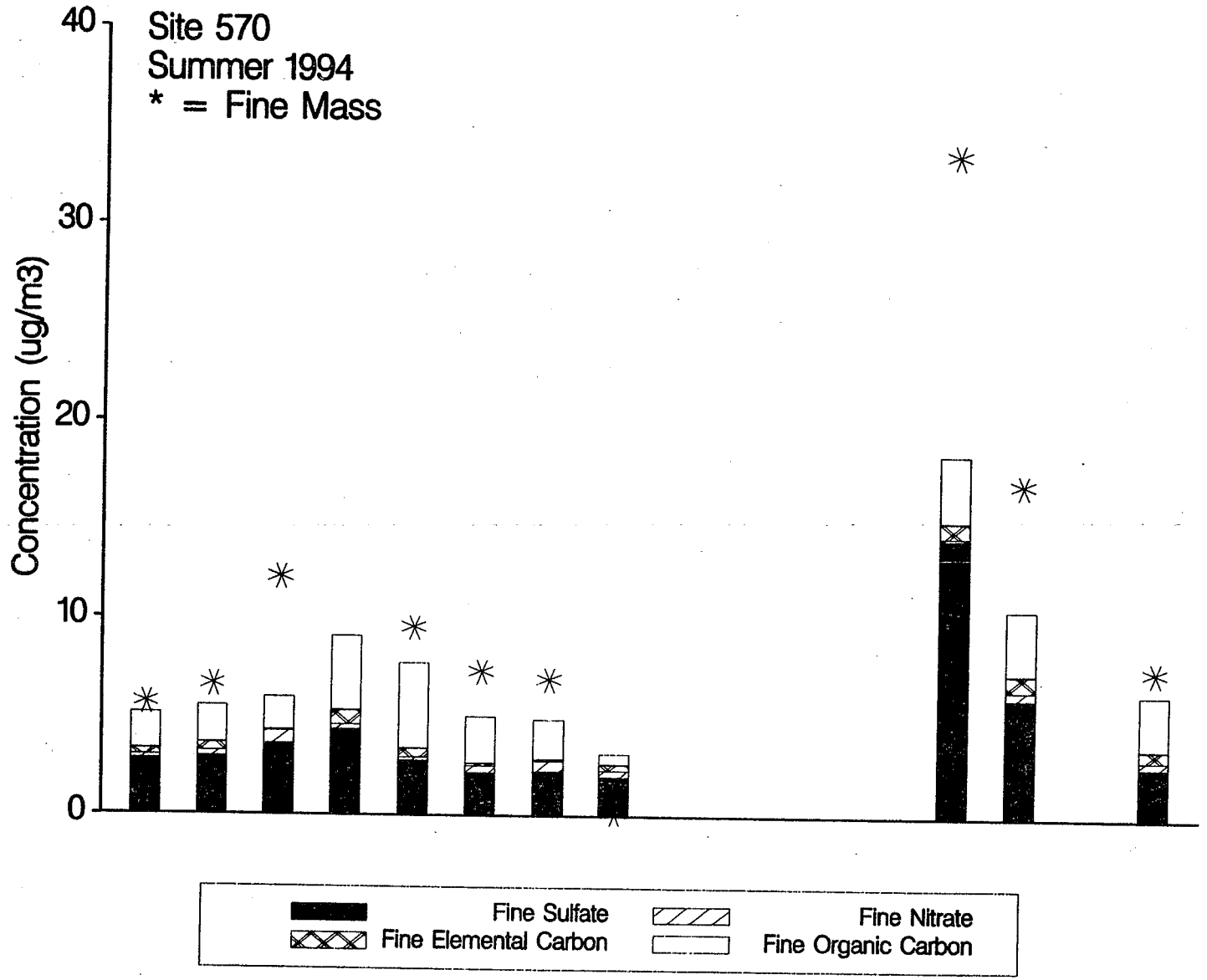


Figure 3-218. Time series bar charts of 24-hour concentrations of fine mass, SO_4^{2-}, NO_3^-, organics, and elemental carbon measured in the summer of 1994 for Site 570

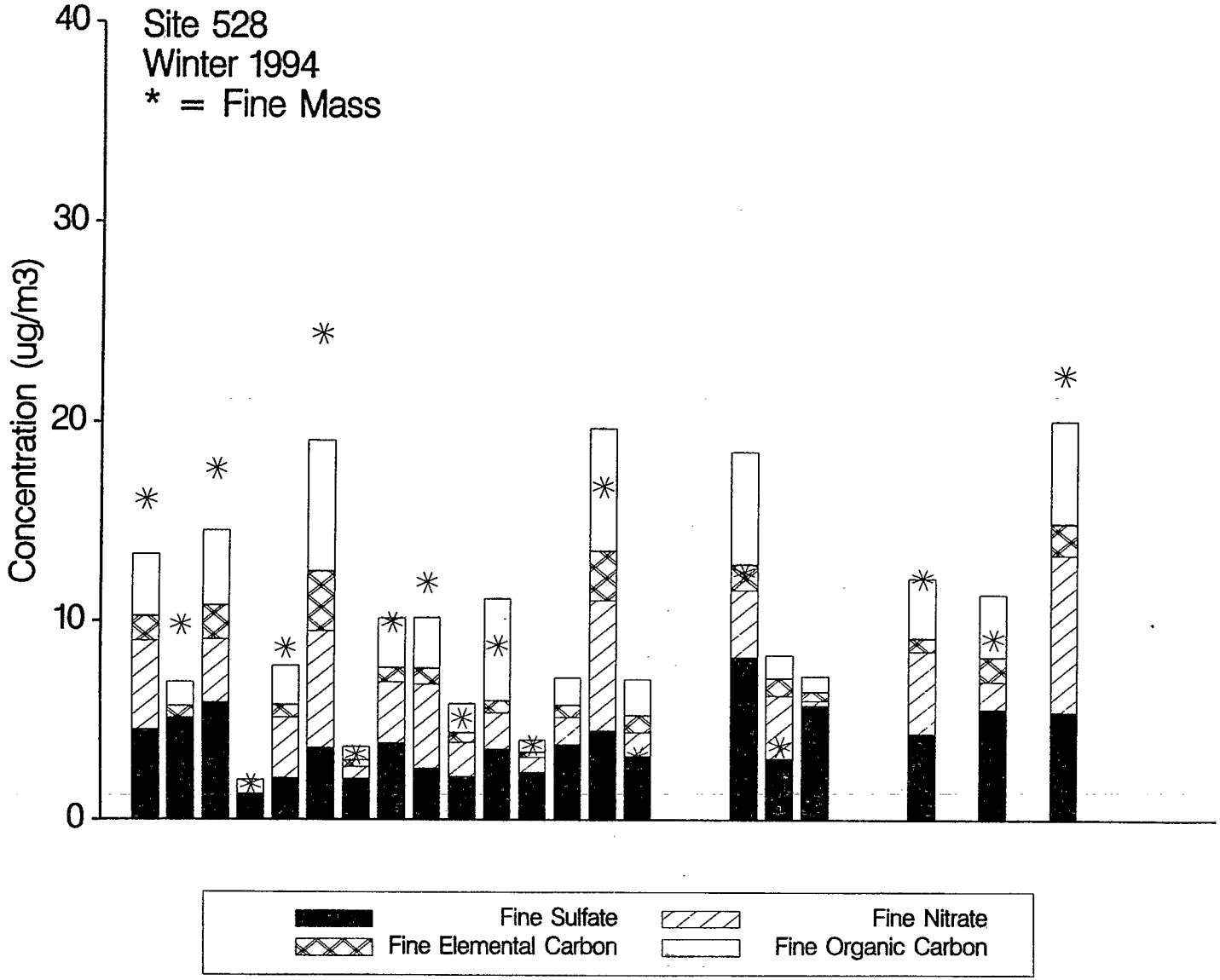


Figure 3-219. Time series bar charts of 24-hour concentrations of fine mass, SO_4^{2-}, NO_3^-, organics, and elemental carbon measured in the winter of 1994 for Site 528

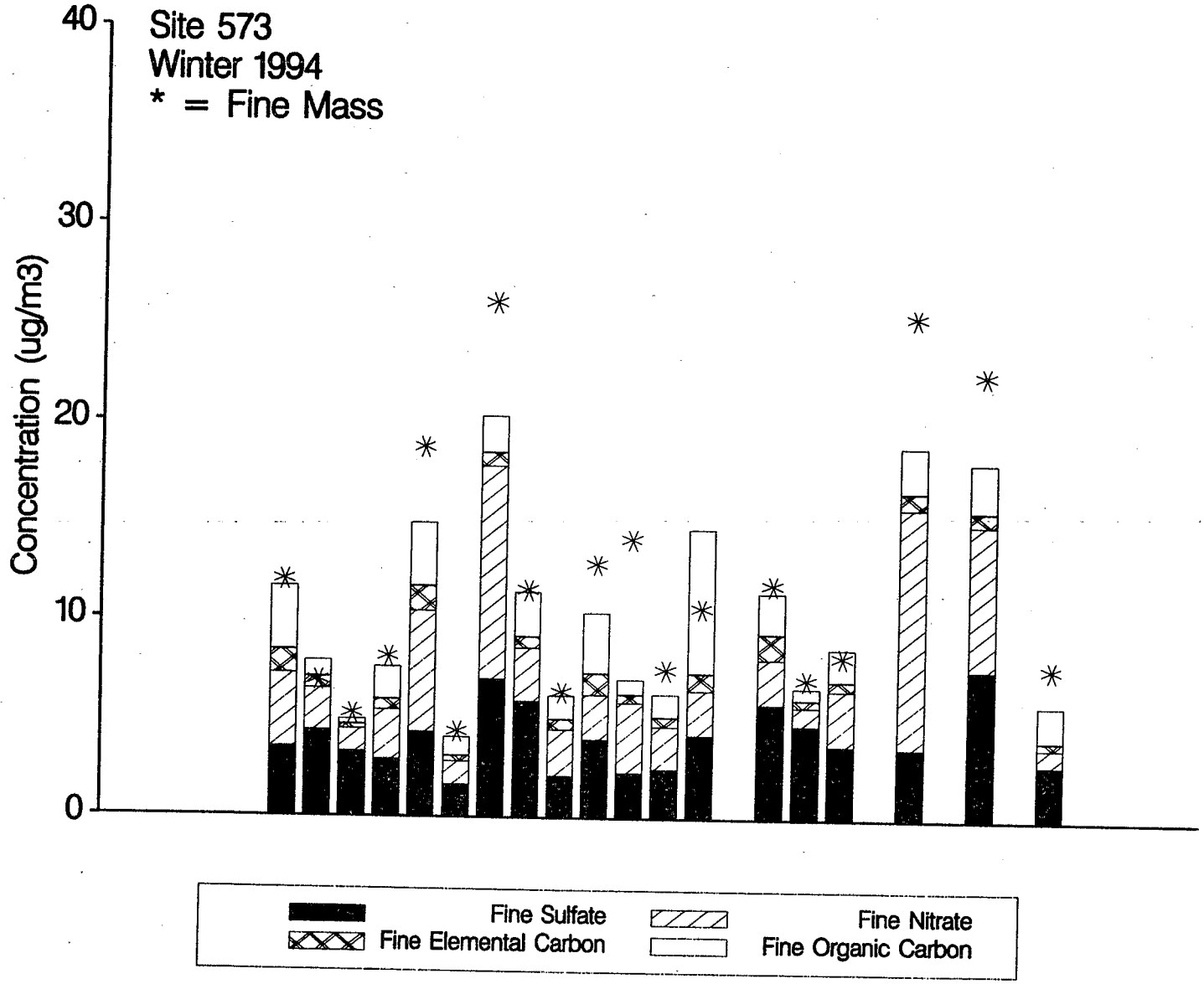


Figure 3-220. Time series bar charts of 24-hour concentrations of fine mass, SO_4^{2-}, NO_3^-, organics, and elemental carbon measured in the winter of 1994 for Site 573

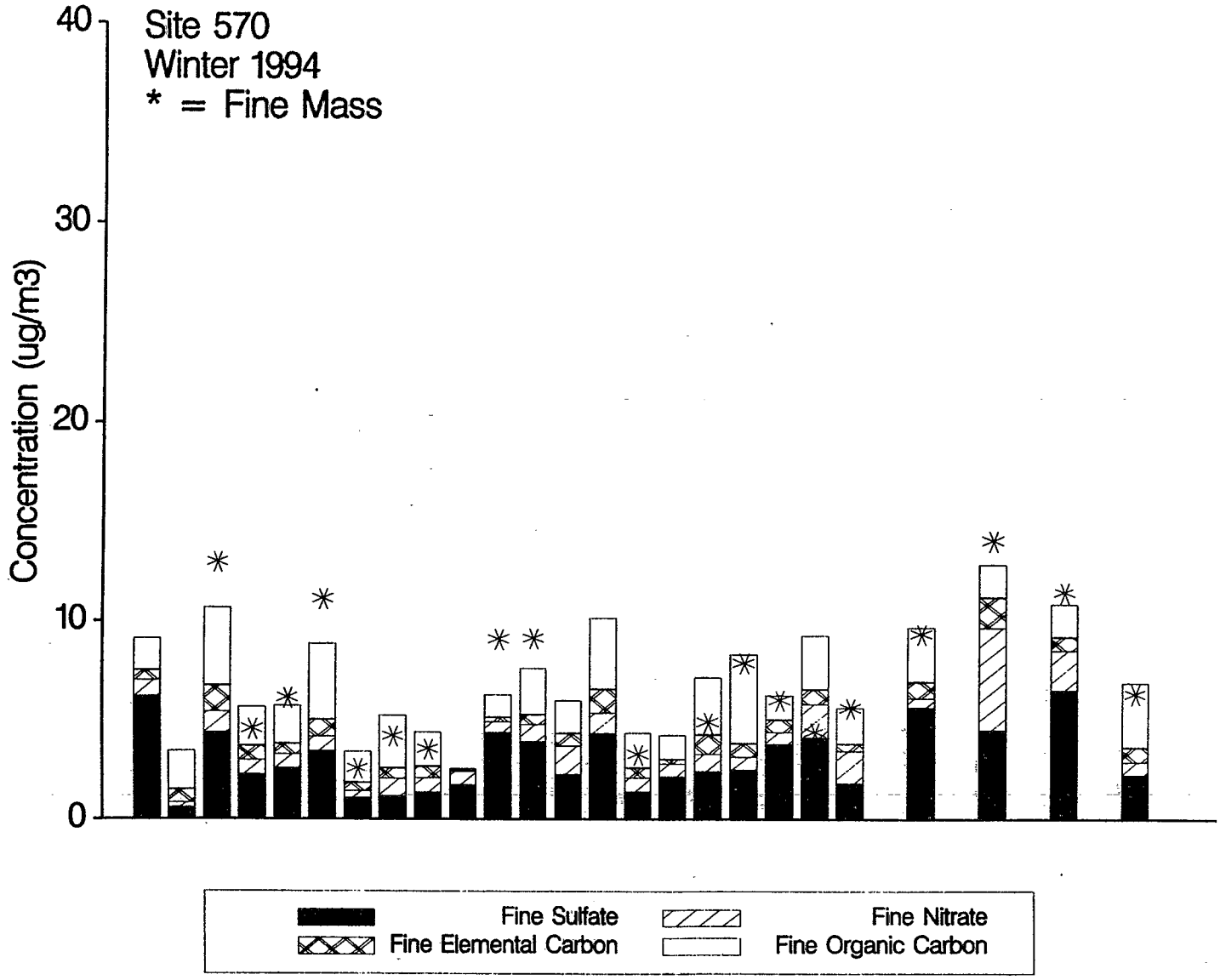


Figure 3-221. Time series bar charts of 24-hour concentrations of fine mass, SO_4^{2-}, NO_3^-, organics, and elemental carbon measured in the winter of 1994 for Site 570

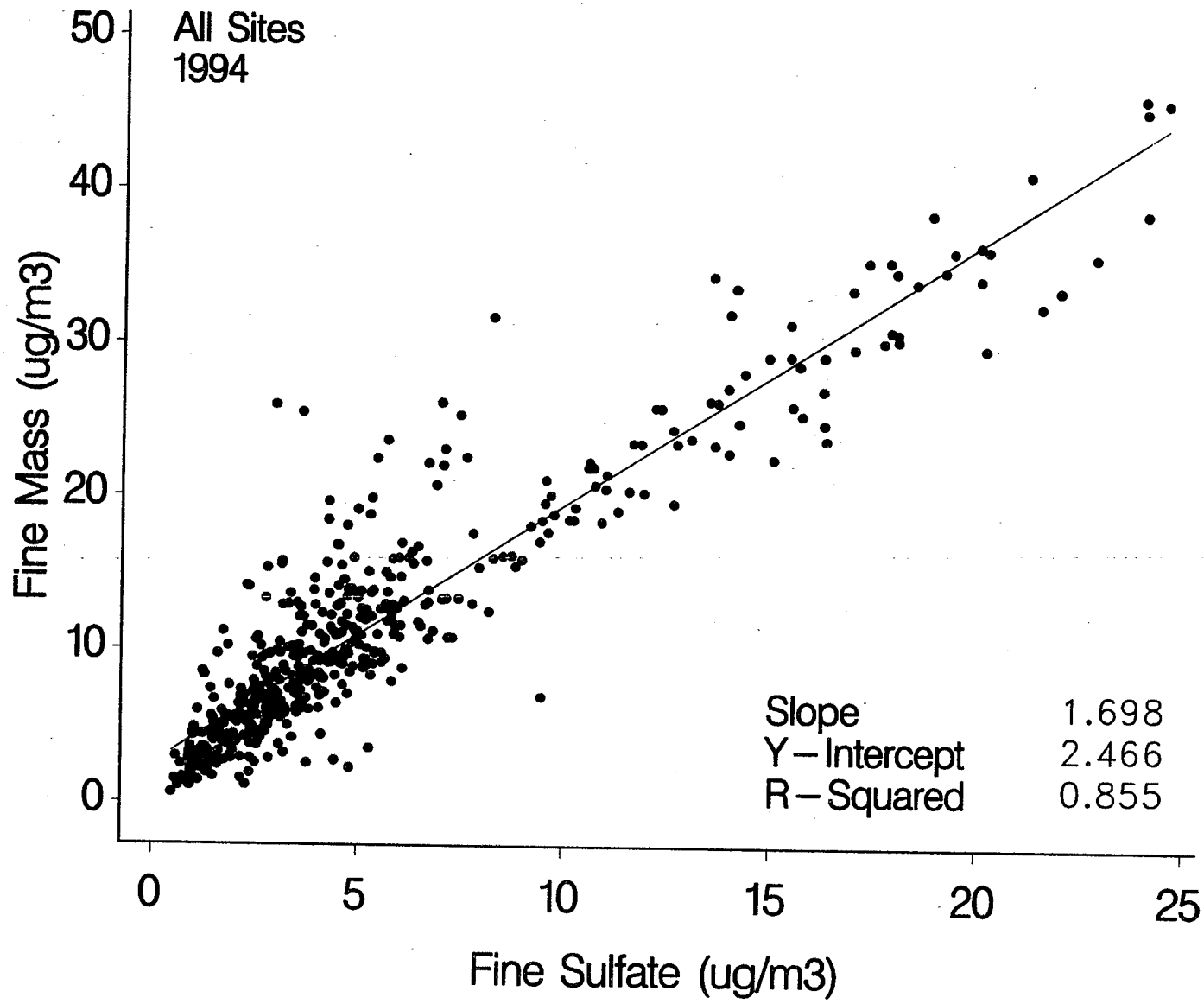


Figure 3-222. Scattergram of 24-hour fine mass and SO_4^{2-} concentrations for all visibility monitoring sites in 1994

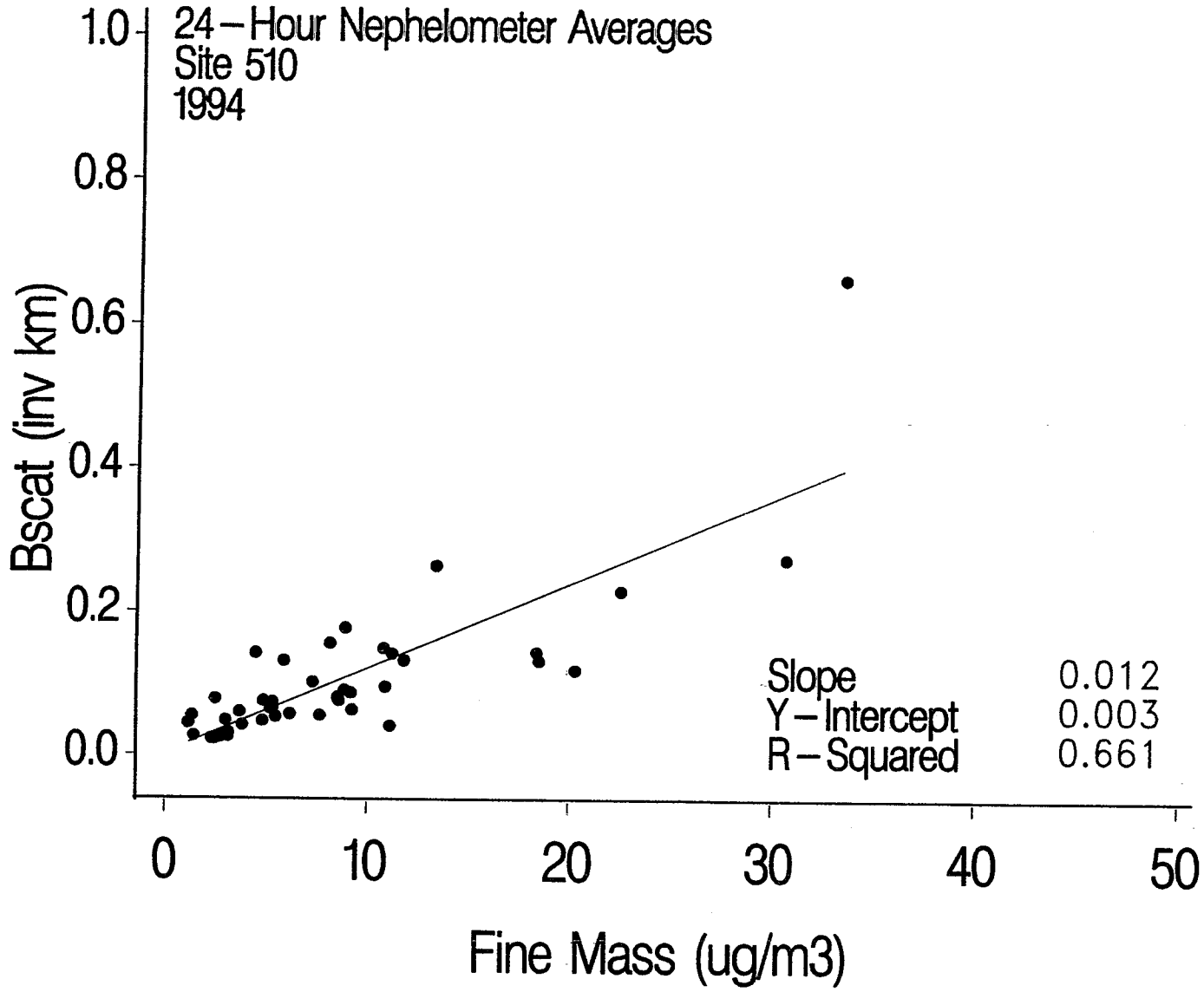


Figure 3-223. Scattergram of 24-hour average B_{scat} and fine mass concentrations measured from a nephelometer at Site 510 in 1994

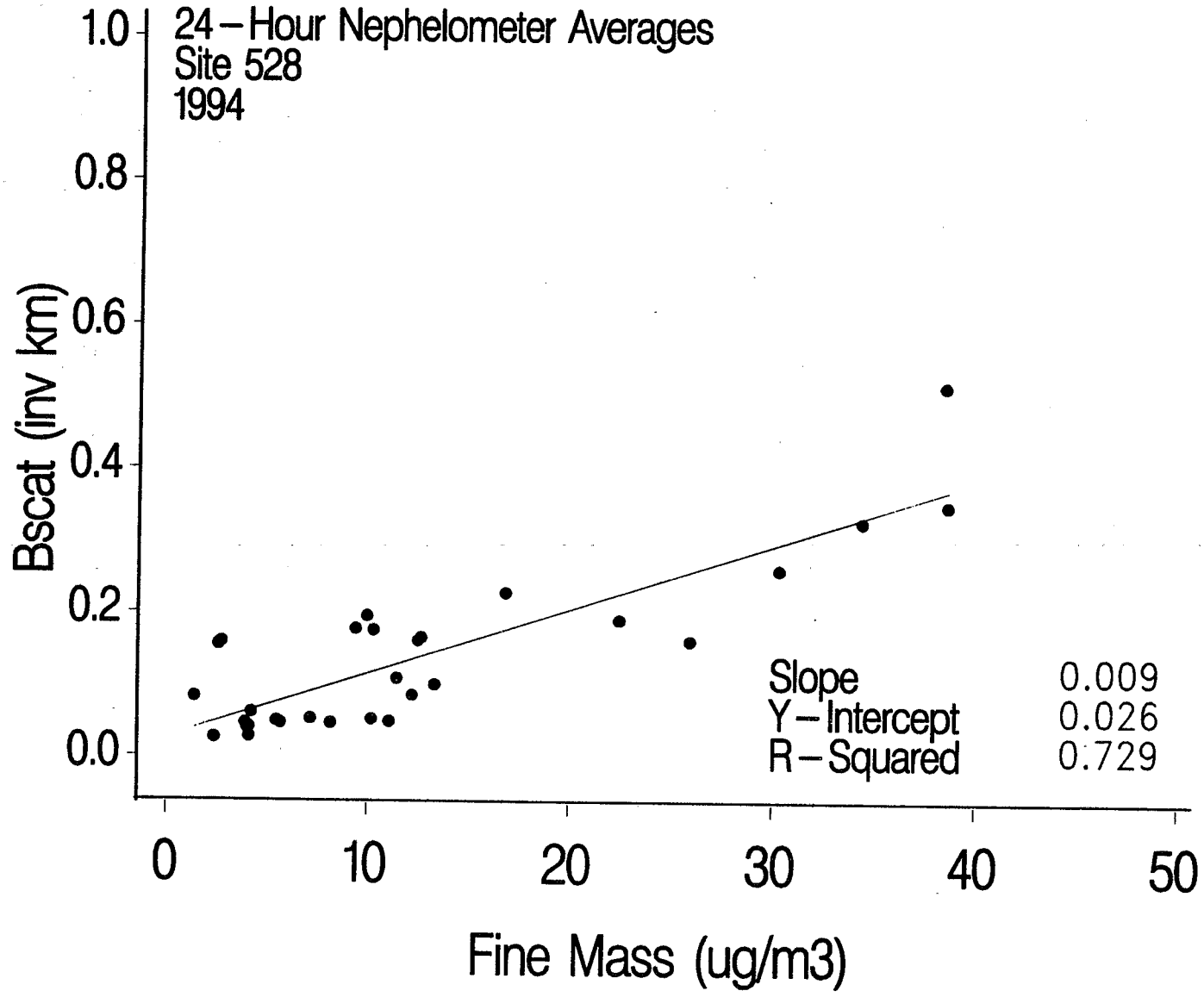


Figure 3-224. Scattergram of 24-hour average B_{scat} and fine mass concentrations measured from a nephelometer at Site 528 in 1994

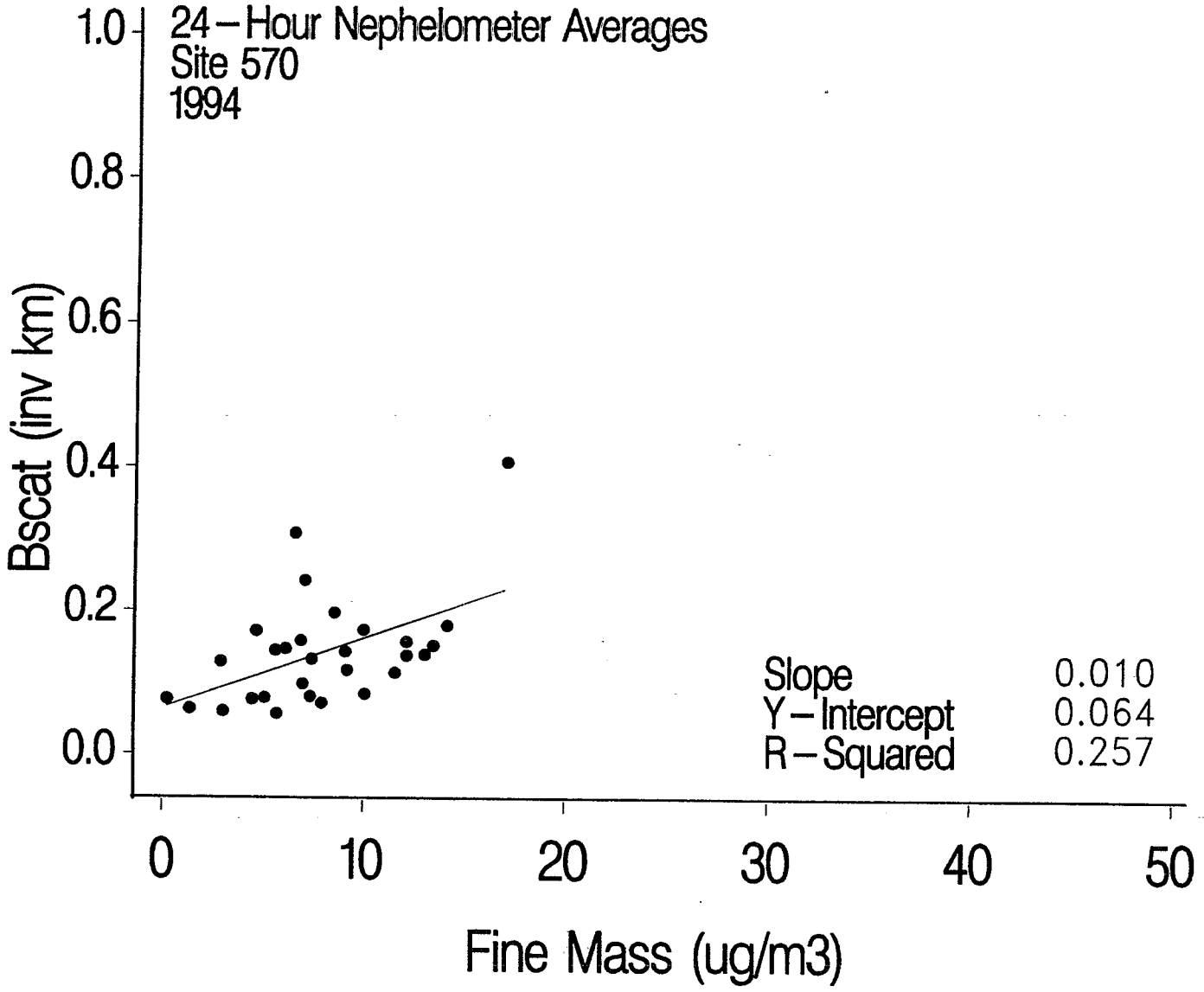


Figure 3-225. Scattergram of 24-hour average B_{scat} and fine mass concentrations measured from a nephelometer at Site 570 in 1994

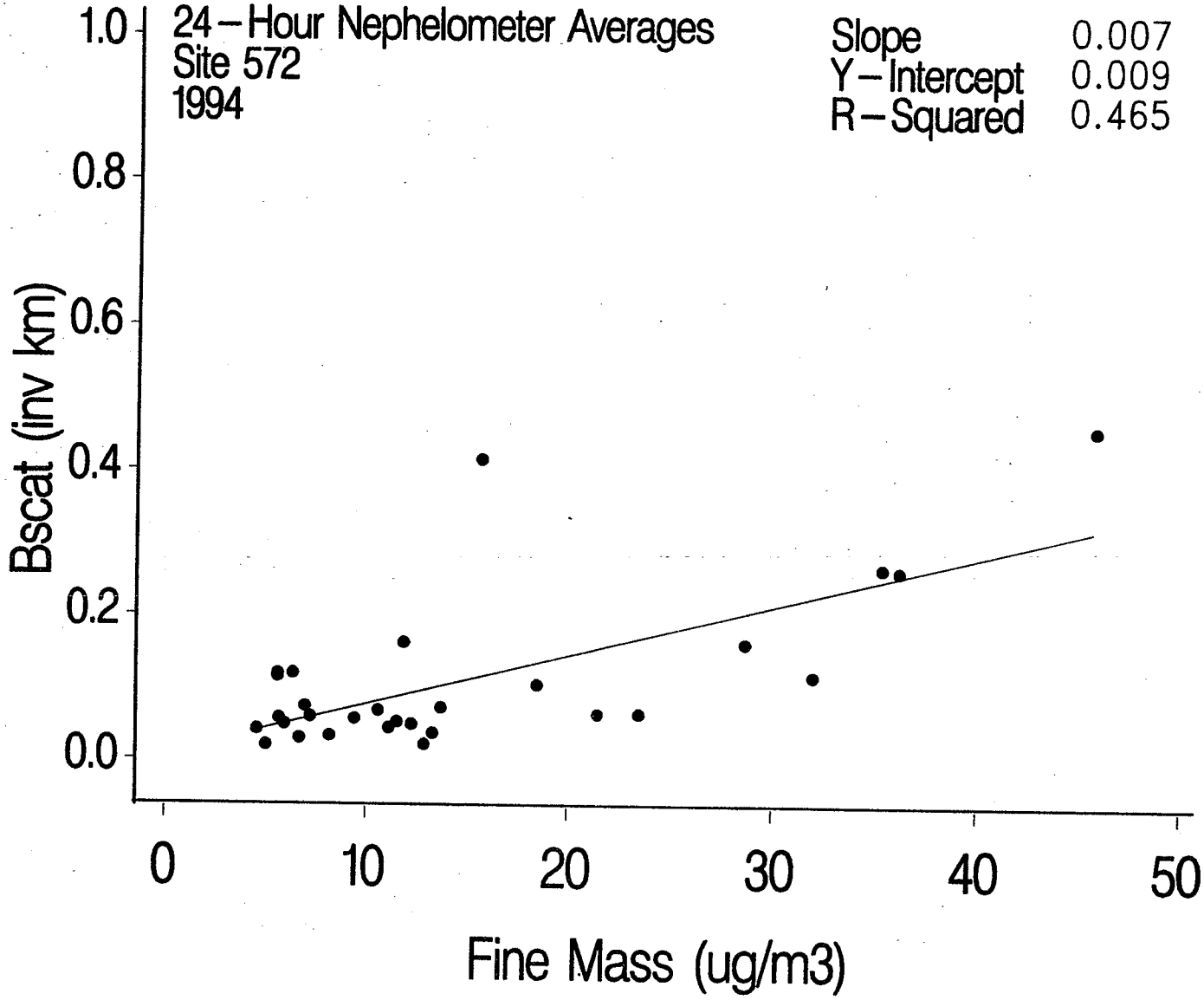


Figure 3-226. Scattergram of 24-hour average B_{scat} and fine mass concentrations measured from a nephelometer at Site 572 in 1994

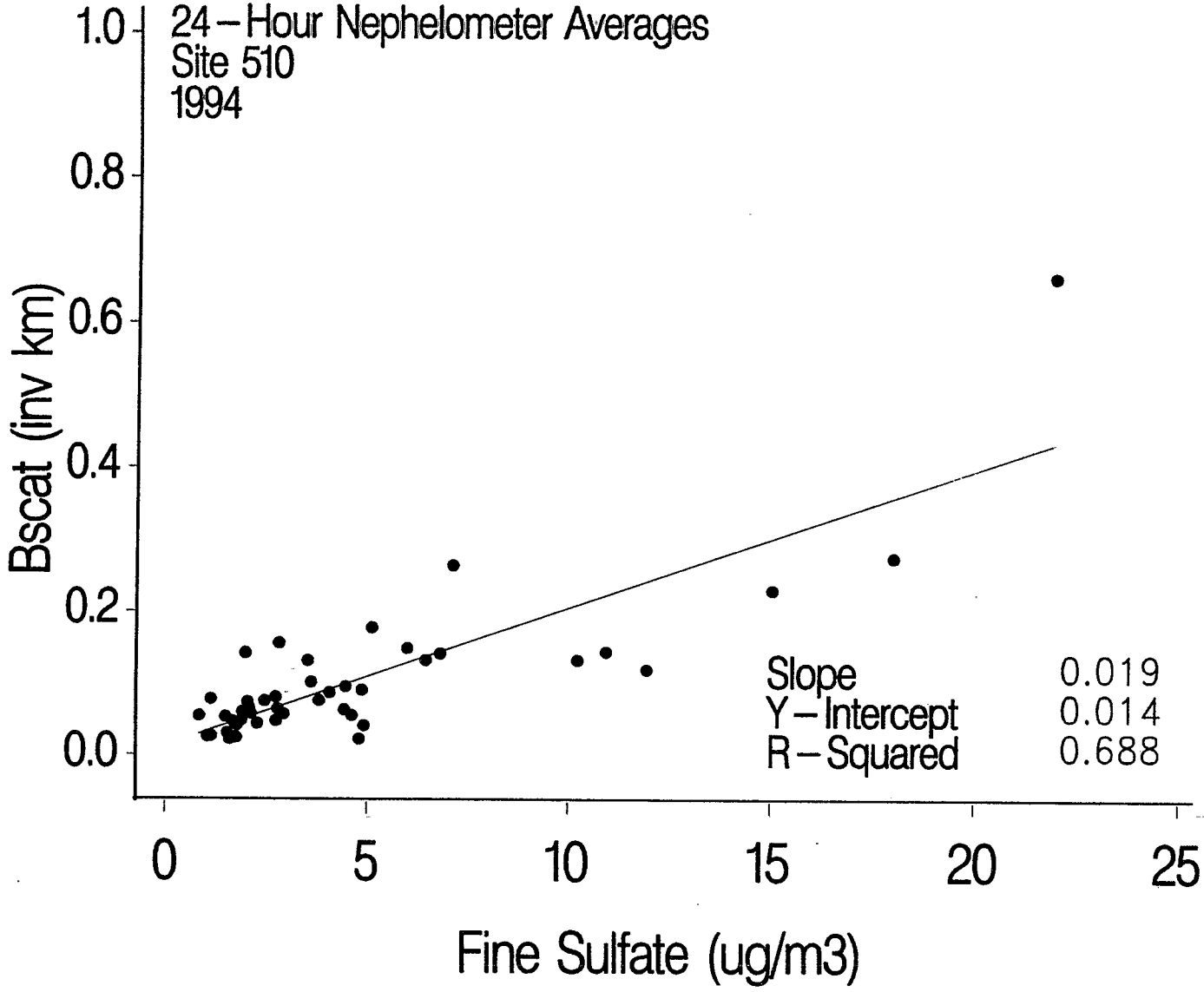


Figure 3-227. Scattergram of 24-hour average B_{scat} and SO_4^{2-} concentrations measured from a nephelometer at Site 510 in 1994

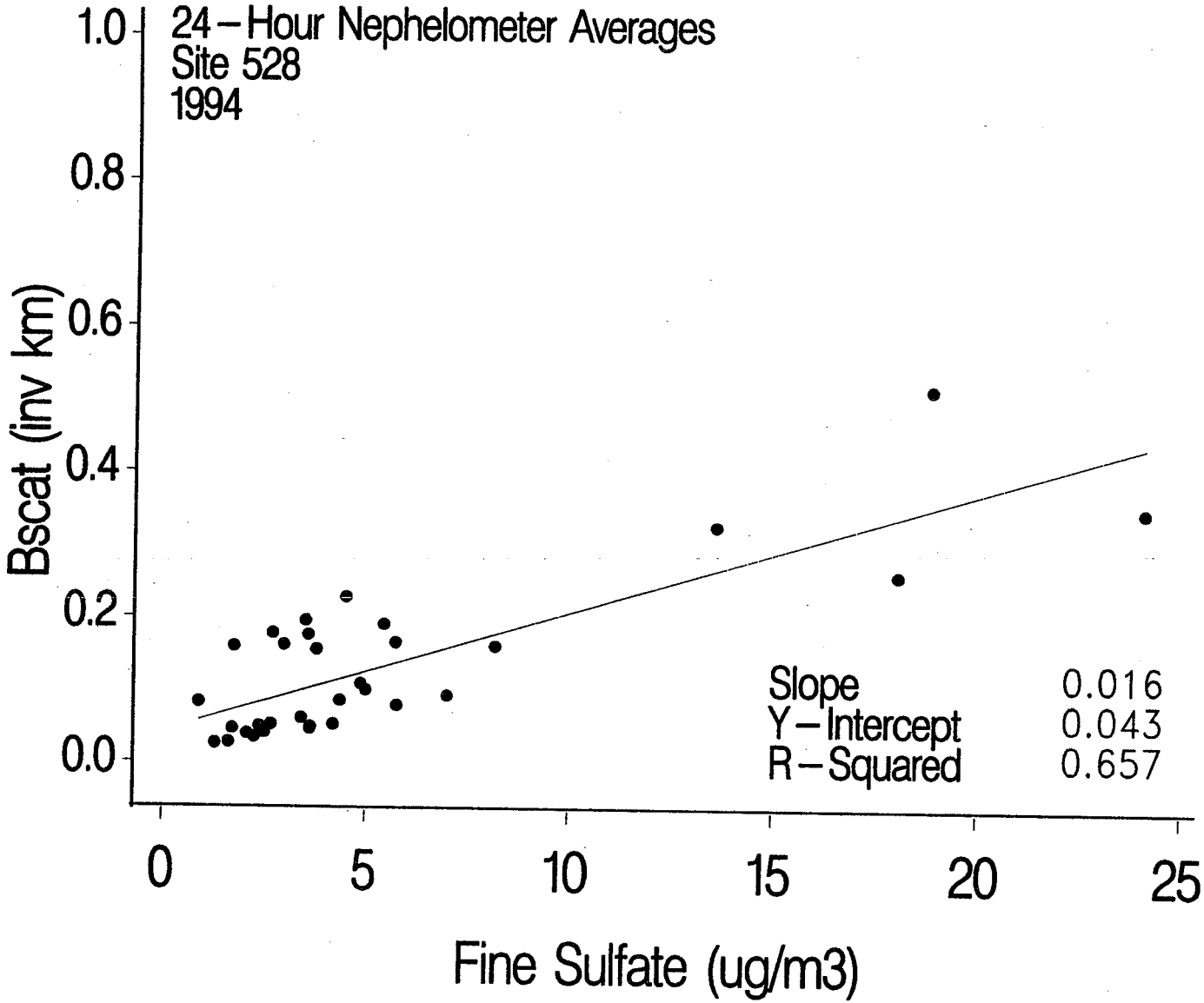


Figure 3-228. Scattergram of 24-hour average B_{scat} and SO_4^{2-} concentrations measured from a nephelometer at Site 528 in 1994

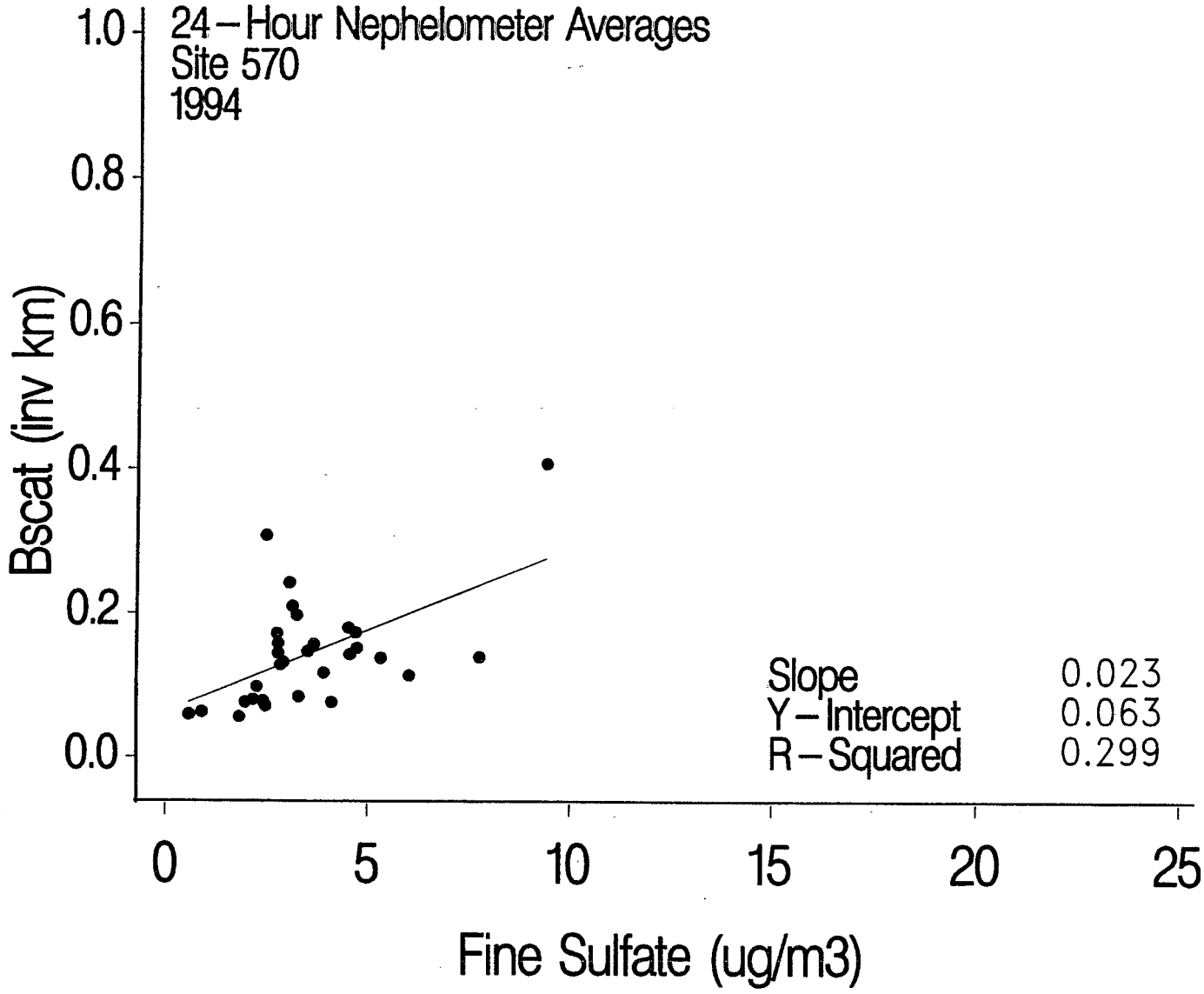


Figure 3-229. Scattergram of 24-hour average B_{scat} and SO_4^{2-} concentrations measured from a nephelometer at Site 570 in 1994

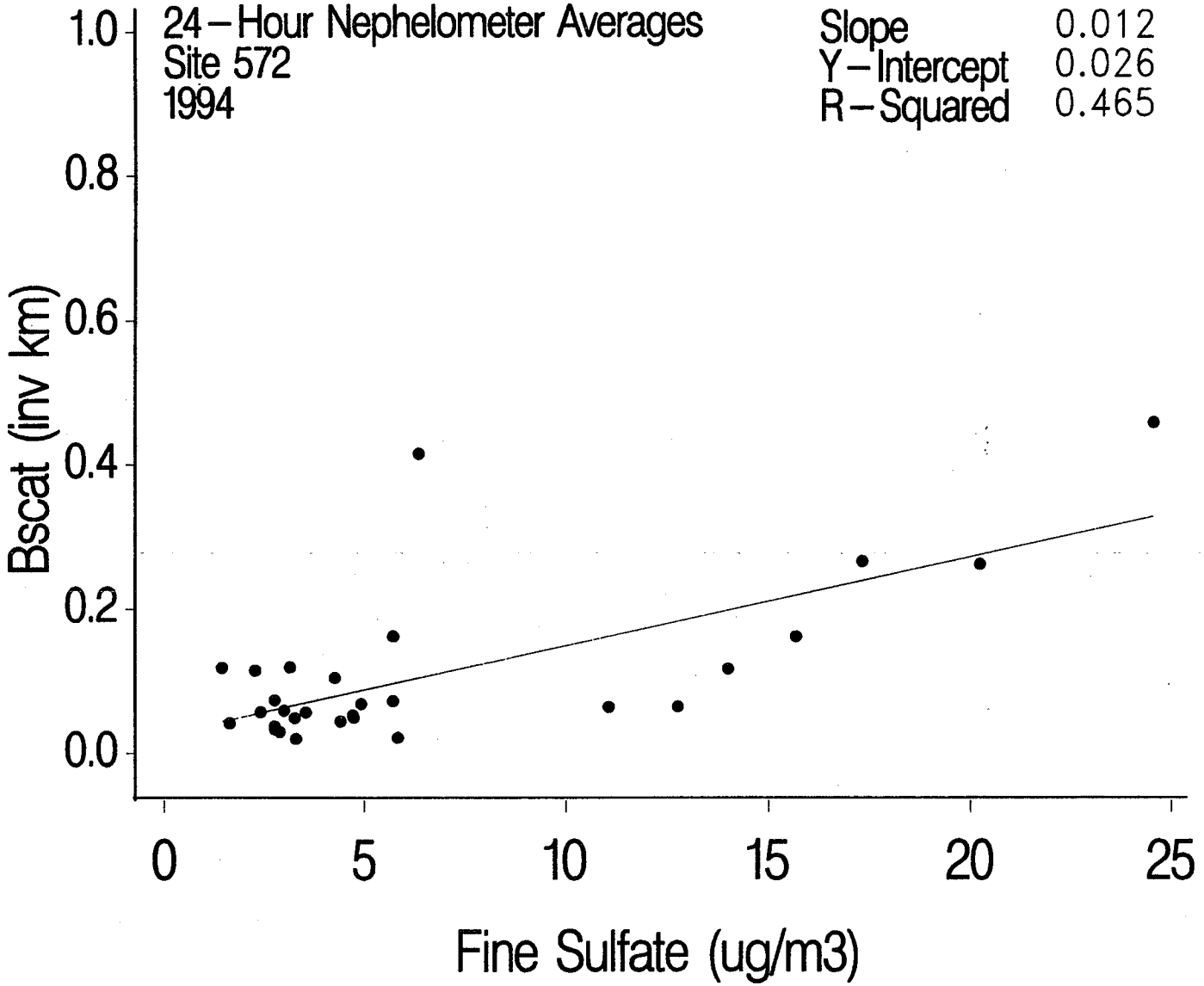


Figure 3-230. Scattergram of 24-hour average B_{scat} and SO_4^{2-} concentrations measured from a nephelometer at Site 572 in 1994

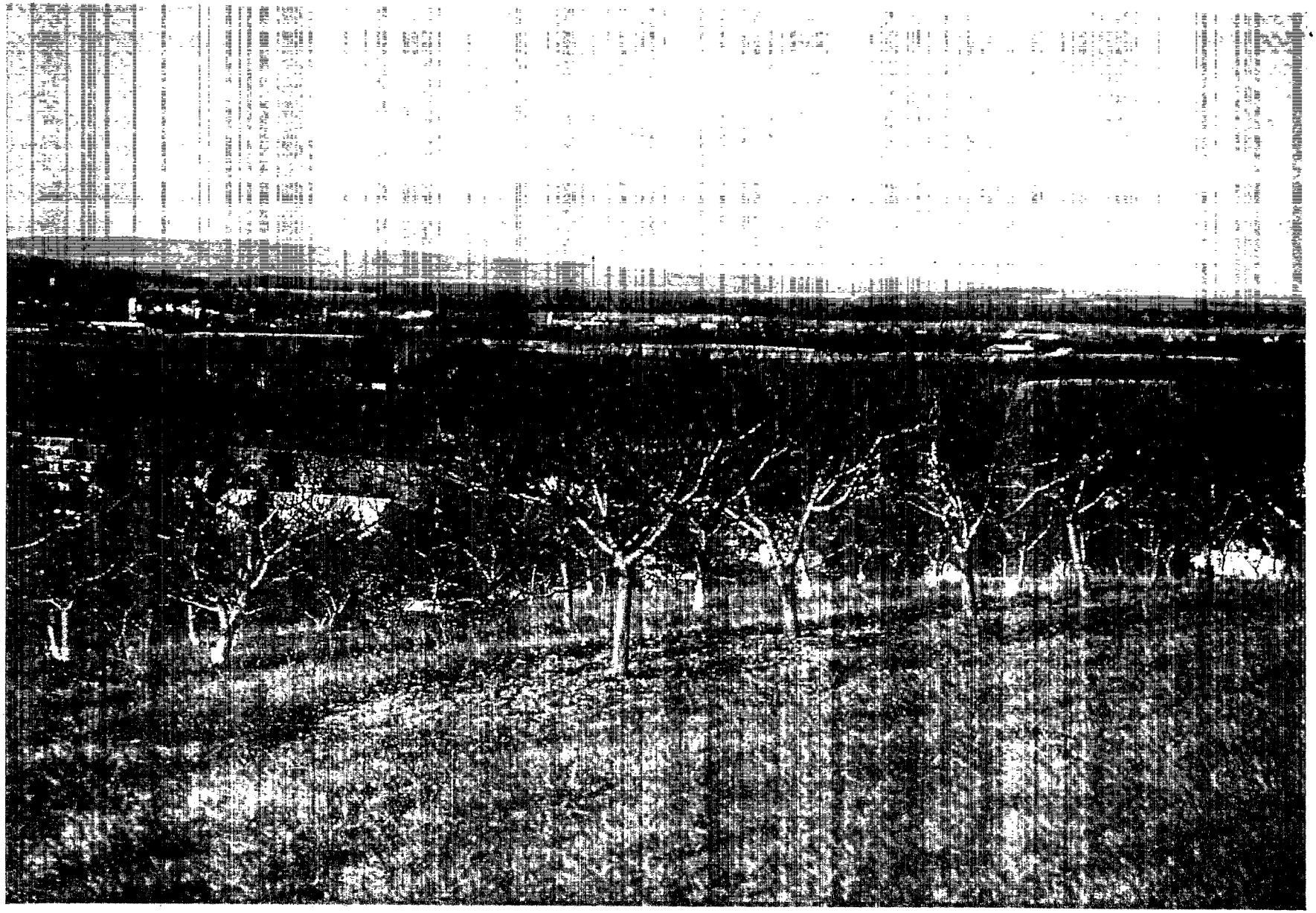


Figure 3-231. Photograph of scenic view at Arendtsville on November 10, 1994

Figure 3-232. Photograph of scenic view at Arendtsville on July 31, 1994

SITE ARRANGEMENT

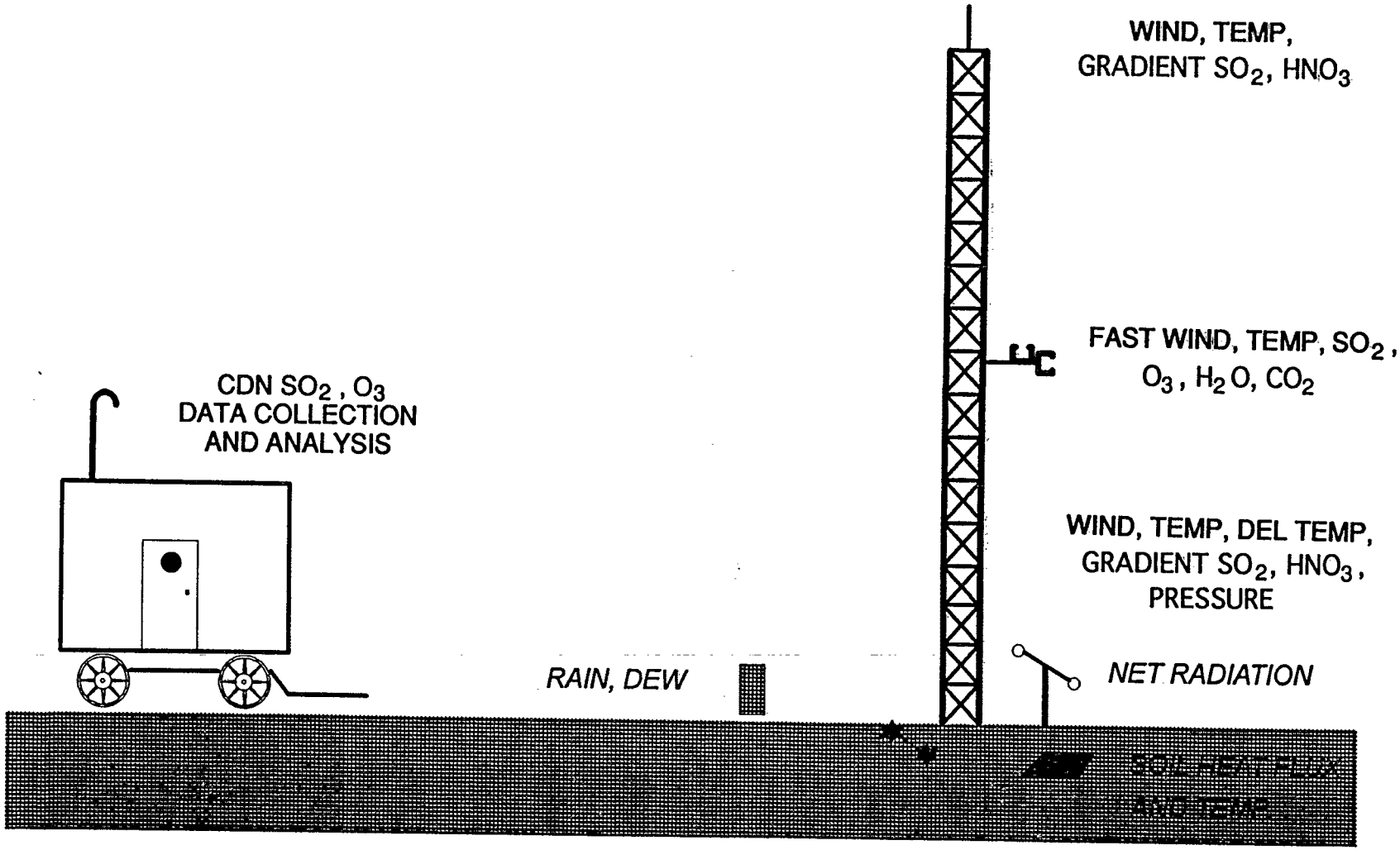


Figure 3-233. Schematic of the mobile dry deposition system

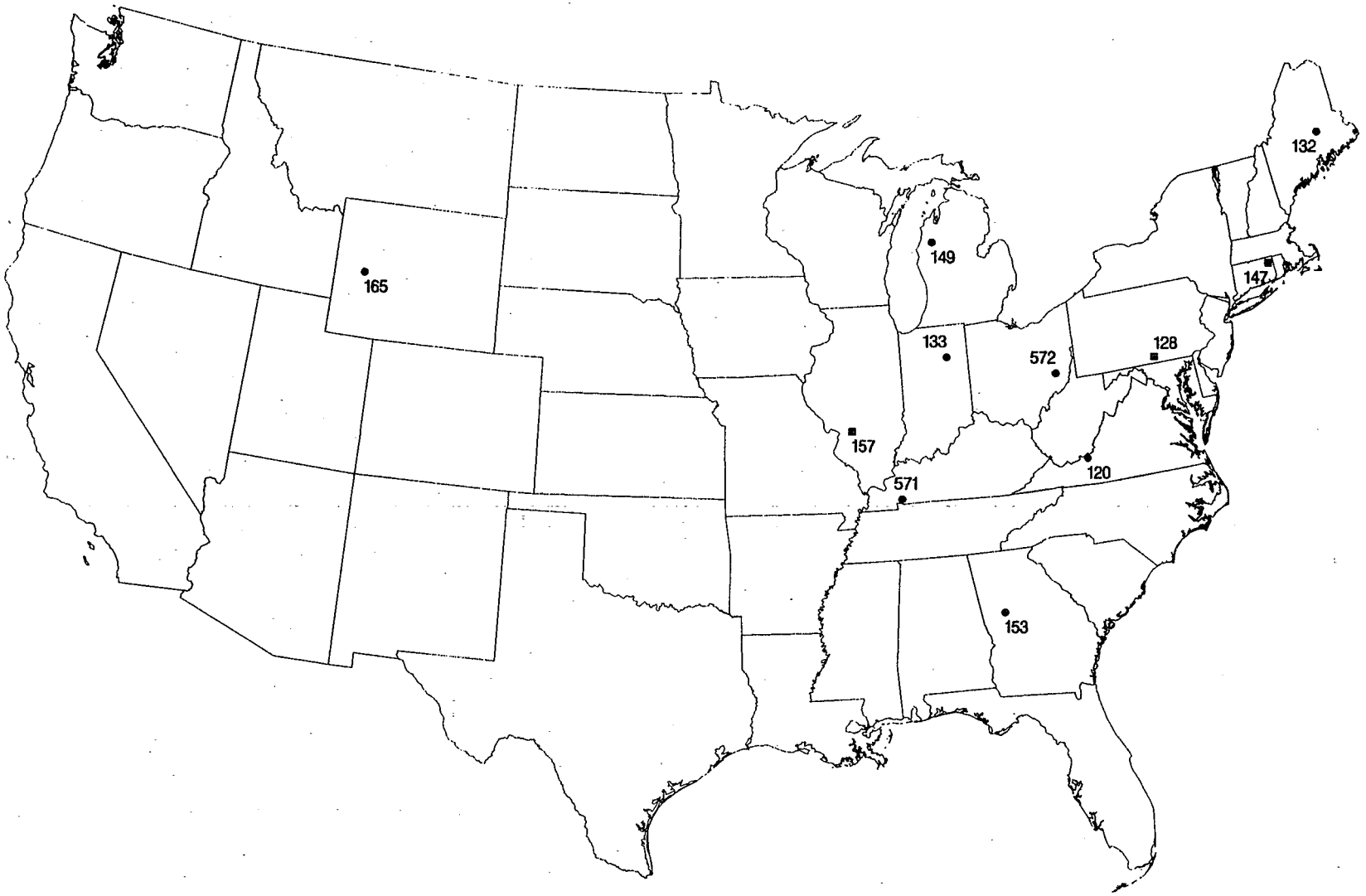


Figure 3-234. Locations of CASTNet sites for the filter pack/annular denuder comparison study

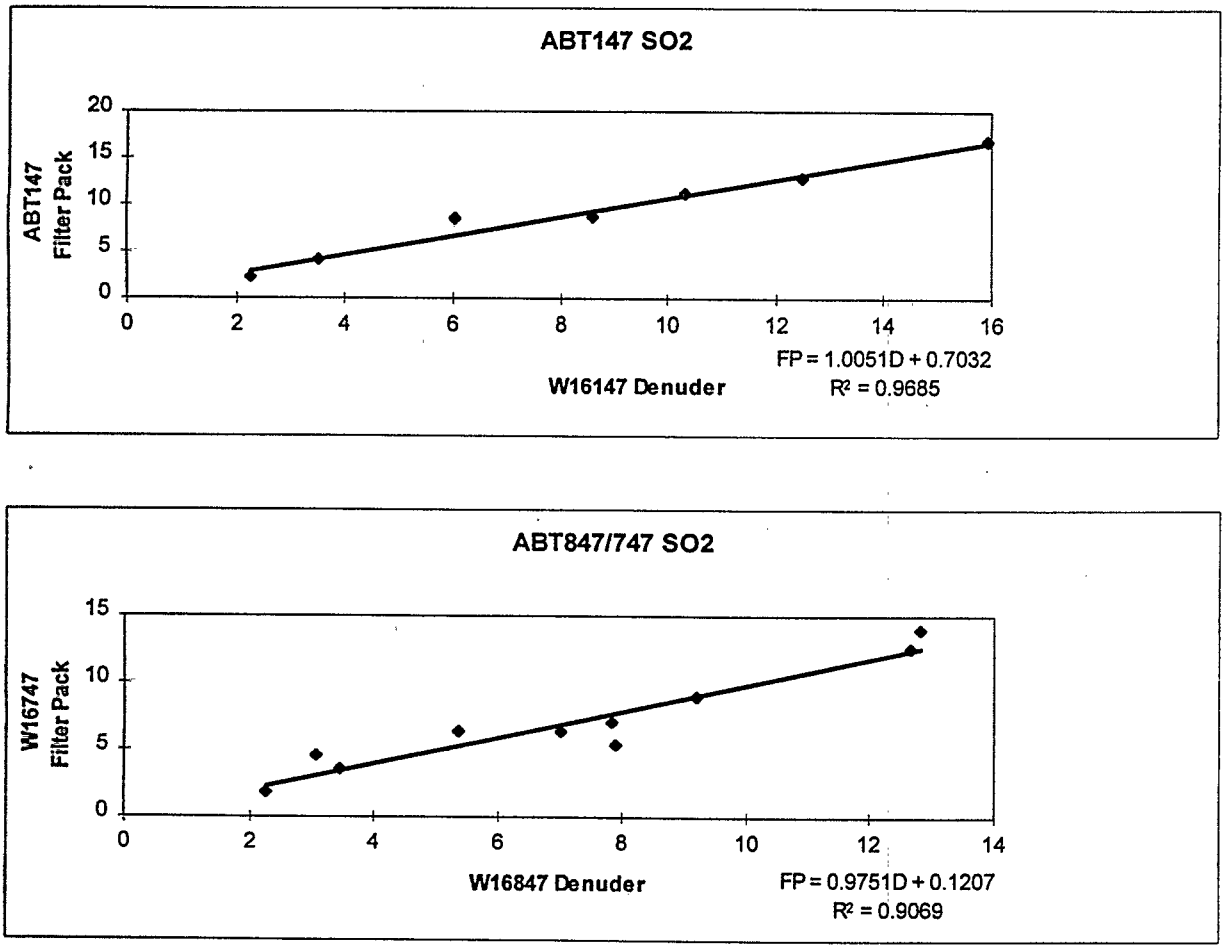


Figure 3-235. Comparison of SO_2 measurements from filter pack and annular denuder systems

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