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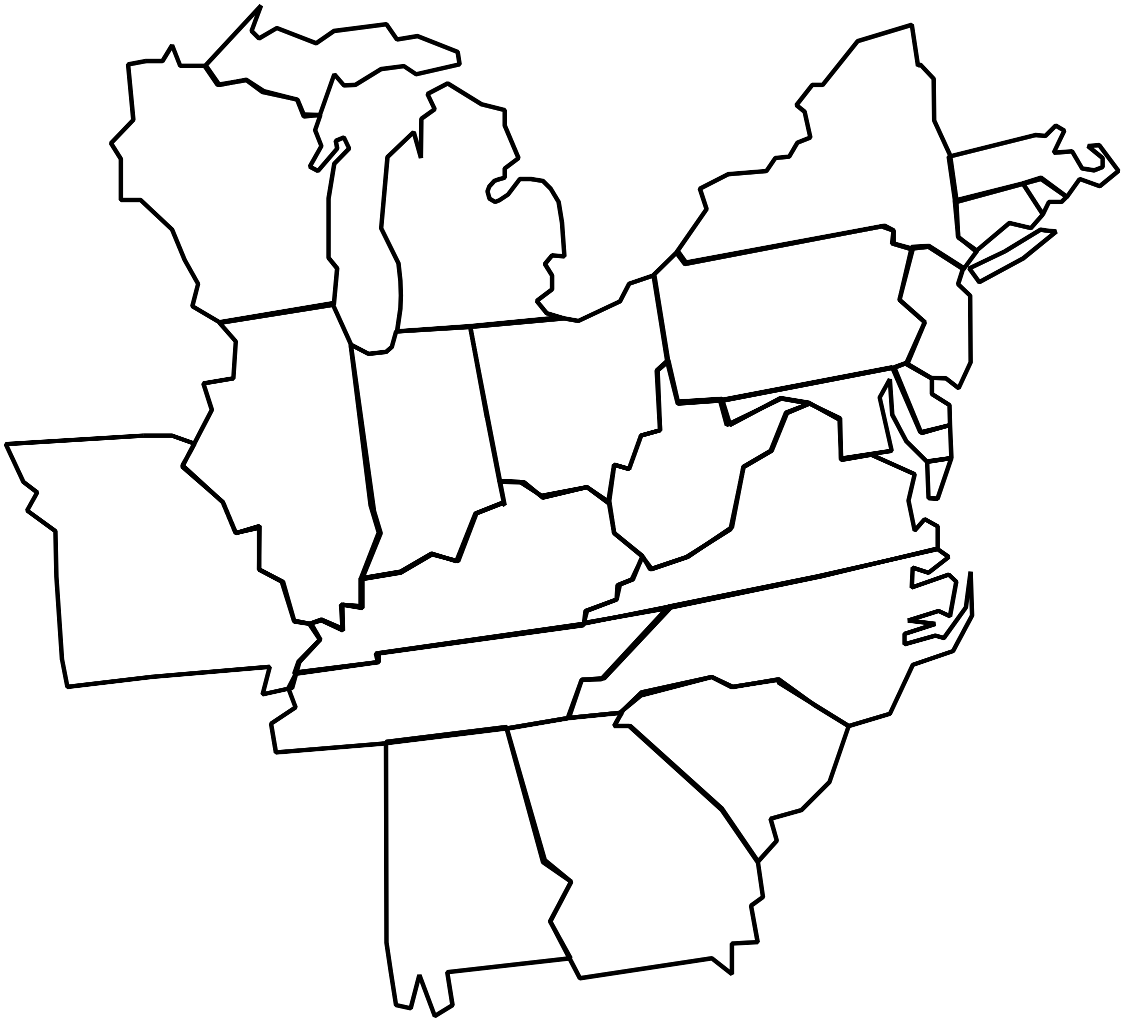
REGULATORY IMPACT ANALYSIS FOR THE NOx SIP CALL, FIP, AND SECTION 126 PETITIONS

Volume 2: Health and Welfare Benefits



REGULATORY IMPACT ANALYSIS FOR THE NOx SIP CALL, FIP, AND SECTION 126 PETITIONS

Volume 2: Health and Welfare Benefits

Prepared by

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Select List of Acronyms and Abbreviations

AFS - AIRS Facility System
AIRS - Aerometric Information Retrieval System
ANPR - Advanced Notice of Proposed Rulemaking
b_{ext} - Total Atmospheric Light Extinction Coefficient
BACT - Best Available Control Technology
BEIS - Biogenic Emissions Inventory System
CAA - Clean Air Act
CAAA - Clean Air Act Amendments of 1990
CAPMS - Criteria Air Pollutant Modeling System
CASAC - Clean Air Scientific Advisory Committee
CASTNet - Clean Air Status and Trends Network
CB - Chronic Bronchitis
CO - Carbon Dioxide
COI - Cost of Illness
COPD - Chronic Obstructive Pulmonary Disease
C-R - Concentration-Response
CRDM - Climatalogical Regional Dispersion Model
CV - Contingent Valuation
dv - Deciview
ECOS - Environmental Council of States
EGUs - Electricity Generating Units
EO - Executive Order
EPA - Environmental Protection Agency
FIP - Federal Implementation Plan
H^+ - Hydrogen Ion
H_2O_2- Hydrogen Peroxide
HNO_3 - Nitric Acid
hr - Hour
IMPROVE - Interagency Monitoring for Protection of Visual Environments
IPM - Integrated Planning Model
Kg/ha - Kilograms Per Hectare
km^2 - Square Kilometer
kWh - Kilowatt Hour
LAER - Lowest Achievable Emissions Rates
lb - Pound
LDs - Loss Days
LRS - Lower Respiratory Symptoms
MCL - Maximum Contaminant Level
mills/kWh - Mills Per Kilowatt Hour
MM4 - Mesoscale Model, version 4
mmBtu - Millions of British Thermal Units
Mm- Megameter
MOU - Memorandum of Understanding
MRAD - Minor Restricted Activity Days
MRRAD - Minor Respiratory Restricted Activity Days
MW - Megawatts

Acronyms and Abbreviations (continued)

MWh - Megawatt Hours
MWTP - Marginal Willingness to Pay
NAA - Nonattainment Area
NAAQS - National Ambient Air Quality Standards
NAPAP - National Acid Precipitation Assessment Program
NCLAN - National Crop Loss Assessment Network
NET - National Emission Trends
NH_3 - Ammonia
NLEV - National Low Emission Vehicle
NMSCs - Nonmelanoma Skin Cancers
NOAA - National Oceanic and Atmospheric Administration
NOx - Oxides of Nitrogen
NO_3 - Nitrate
NPR - Notice of Proposed Rulemaking
NPS - Non-Point Source
NSA - Nitrate, Sulfate, and Ammonium Components
NSPS - New Source Performance Standards
NSR - New Source Review
O_3 - Ozone
OMB - Office of Management and Budget
OMS - Office of Mobile Sources
O&M - Operation and Maintenance
OTAG - Ozone Transport Assessment Group
OTC - Ozone Transport Commission
OTR - Ozone Transport Region
PM - Particulate Matter
ppm - Parts Per Million
PRA - Paperwork Reduction Act of 1995
PSD - Prevention of Significant Deterioration
RIA - Regulatory Impact Analysis
RACT- Reasonably Available Control Technology
RADM - Regional Acid Deposition Model
RFA - Regulatory Flexibility Act
RMF - Regional Model Farm
RPM - Regional Particulate Model
SAB - Science Advisory Board
SBA - Small Business Administration
SBREFA - Small Business Regulatory Enforcement Fairness Act of 1996
SNPR - Supplemental Notice of Proposed Rulemaking
SO_2 - Sulfur Dioxide
SO_4^{2-} - Sulfate Ion
SOA - Secondary Organic Aerosols
S-R - Source-Receptor
TAMM - Timber Assessment Market Model
tpd - Tons Per Day
tpy - Tons Per Year
TSP - Total Suspended Particulates

Acronyms and Abbreviations (continued)

$\mu g/m^3$ - Micrograms Per Meter Cubed
UAM-V - Urban Airshed Model - Variable Scale
UMRA - Unfunded Mandates Reform Act
URS - Upper Respiratory Symptoms
USDA - United States Department of Agriculture
UV-B - Ultraviolet-B Radiation
VOCs - Volatile Organic Compounds
WLDs - Work Loss Days
WTP - Willingness to Pay

EXECUTIVE SUMMARY

EPA has finalized the nitrogen oxides (NOx) State implementation plan (SIP) call rule. The "NOx SIP call" requires selected eastern States to take actions to reduce emissions of NOx that contribute to nonattainment of ozone standards in downwind States. For the purposes of this analysis, EPA has modeled an illustrative State implementation scenario. This Regulatory Impact Analysis (RIA) and associated analyses are intended to generally inform the public about the potential costs and benefits that may result from this scenario, but specific State actions will ultimately determine the actual costs and benefits of the NOx SIP call.

At the same time that EPA promulgates the NOx SIP call, EPA is proposing NOx Federal implementation plans (FIPs) that may be needed if any State fails to comply with the final NOx SIP call. EPA is also proposing a response to Section 126 petitions which were filed by eight northeastern States asking EPA to address air pollution transported from upwind States. Pursuant to Executive Order 12866, this RIA presents the potential costs, economic impacts and benefits of these rulemakings.

The existing 1-hour and new 8-hour national ambient air quality standards (NAAQS) for ozone set levels necessary for the protection of human health and the environment. Under the Clean Air Act Amendments of 1990 (CAAA), attainment of these standards depends on the implementation of State-specific pollution control strategies contained in SIPs, in conjunction with EPA promulgation of national controls for some sources of pollution, to reduce NOx and volatile organic compound (VOC) emissions. The NOx SIP call creates an effective, efficient and equitable approach for EPA and the States to promote attainment with the current and new ozone standards.

In the NOx SIP call, EPA is setting ozone season NOx budgets for States that are in the SIP call region. In nearly all cases, these budgets will require States to seek lower emissions from their sources to enable the State to meet its budget level. To arrive at what the NOx budgets should be for the States, the Agency considered alternative levels of reductions that States could reasonably require of selected stationary sources to reduce their summer NOx emissions in the future. The final set of sources that EPA based the State NOx budgets on includes large electricity generating units, industrial boilers and combustion turbines, stationary internal combustion engines, and cement manufacturing operations. Table ES-1 lists the major regulatory alternatives that EPA considered for each of the above sectors when it determined State-level NOx emissions budgets in the NOx SIP call. The shaded areas in the table show the options that EPA selected based largely on the Agency's determination (as explained in the preamble to this rulemaking) that the ozone season NOx controls for a sector were highly cost-effective and could be reasonably implemented in the near future. For the electricity generating units and industrial boilers and combustion turbines, the Agency estimates the costs and emissions changes based on an emissions cap-and-trade program. For the remaining sectors, EPA based its analysis on States placing direct controls on the units covered.

In this rule, EPA has offered to administer an emissions trading program for the States. However, each State is free to join the program, or alternatively set up their own program to meet their NOx budget. Therefore, the actual NOx SIP call costs could vary from those that EPA estimates for the approach on which it based the NOx budgets.

Table ES-1
Regulatory Alternatives by Source Category Groupings
for the NOx SIP Call

Electricity Generating Units (EGUs)--Emissions Budgets Based on a NOx Limit of:	**Non-Electricity Generating Units (non-EGUs)**	
	Industrial Boilers and Combustion Turbines--Emissions Budgets Based on a Reduction from Uncontrolled Levels of:	**All Other Stationary Sources--Emissions Budgets Based on Highest Ozone Season NOx Reduction Achievable without a Source Paying More Than:**
0.25 lb/mmBtu*	40%	$1,500/ton
0.20 lb/mmBtu		$2,000/ton
0.15 lb/mmBtu in Northeast; 0.20 lb/mmBtu in Midwest & Southeast	50%	$3,000/ton
0.12 lb/mmBtu in Northeast; 0.15 lb/mmBtu in Midwest; 0.20 lb/mmBtu in Southeast	**60%**	$4,000/ton
0.15 lb/mmBtu	70%	**$5,000/ton**
0.12 lb/mmBtu		

* See Chapter 1 for a breakdown of the States covered in the NOx SIP call

Emission Reductions, Costs, and Cost-effectiveness

Table ES-2 summarizes EPA estimates of the emission reductions, costs, and cost-effectiveness for the regulatory approach that EPA selected as the basis for the NOx SIP Call's NOx budgets. (Please note: Since these estimates were calculated EPA has fine-tuned its estimates of the NOx budgets and an addendum to this executive summary provides revised emission reduction, cost and cost-effectiveness information). Overall, 82% of the emission reductions expected under this regulatory alternative are expected to come from the electric power industry, at an average ozone season cost-effectiveness of $1,468 per ton. The table indicates the estimates of direct control costs for sources including costs associated with emissions monitoring and reporting. The table also indicates the total administrative costs to State governments and EPA. In EPA's analysis to support this rule, the Agency has shown that for the electric power industry, the largest source of emissions for which it considered controls, a single trading program across the SIP call region can provide a similar reduction to what direct command-and-control requirements would accomplish, but do the job at lower cost. For this reason, the Agency is encouraging States to participate in the trading program that it plans to administer.

Table ES-2
Estimate of Emission Reductions, Total Annual Costs, and Cost-Effectiveness in 2007 of the EPA's Selected Approach to NOx SIP Call

Sector	Ozone Season NOx Emission Reductions (1,000 tons)	Total Annual Cost (millions 1990$)	Average Ozone Season Cost-Effectiveness ($ per ozone season ton)
Electricity Generating Units [a]	938	$1,378	$1,468
Industrial Boilers and Turbines [b]	104	$153	$1,467
Internal Combustion Engines [c]	83	$100	$1,215
Cement Manufacturing [c]	16	$24	$1,458
Administrative Costs for EGUs	▨	$6	▨
Administrative Costs to States and EPA		$2	
Total	**1,141**	**$1,660[d]**	

[a] Does not include additional monitoring costs (see later row).
[b] Includes additional monitoring and other administrative costs associated with participating in the NOx emissions trading program.
[c] Includes additional monitoring and other administrative costs associated with the SIP call rule
[d] Numbers do not add due to rounding

Economic Impacts

EPA considered what the economic impacts could be, if States implemented the regulatory approach that EPA used to calculate the NOx SIP call budgets for electricity generating units. Electricity prices could potentially rise in the NOx SIP call region by as much as 1.6 percent in 2007, if the power industry is pricing its power on the basis of marginal costs in a fully competitive environment. The price increase will be less, if these assumptions regarding the nature of the competitive environment do not hold. There will be more new electric generation capacity built in response to the rule than will retire early (there will be little generation capacity that closes). On net, EPA expects this NOx SIP call to create more new jobs (from pollution control operations and increased natural gas use) than it reduces (due to a small decline in forecasted coal demand).

The analysis of non-EGU sources indicates that fewer than 5% of potentially affected firms experience costs in excess of 1% of revenues, and just over 2% of potentially affected firms experience costs in excess of 3% of revenues. EPA also examined the potential affect of the NOx SIP call on small entities that meet the Small Business Administration's definition of "small." The Agency adopted several ways of minimizing potential impacts on small entities for the final NOx SIP call rulemaking. Of the nearly 1,200 small entities (both EGU and non-EGU) in the NOx SIP call region that have large NOx emissions sources, only 150 are potentially affected by the SIP call rule, and only 41 have potential compliance costs in excess of 1% of total revenues. EPA expects States to use these results to help them design control strategies that will reduce or eliminate adverse impacts on small entities.

Benefits

The estimated change in the incidence of health and welfare effects is assessed for several modeled air quality scenarios. The estimated changes in incidence are then monetized by multiplying the estimated change in incidence of each endpoint by its associated dollar value of avoiding an occurrence of an adverse effect. These endpoint-specific benefits are then summed across all affected areas to derive an estimate of total benefits. Because there are potentially significant categories for which health and welfare benefits are not quantified or monetized due to a lack of modeling and economic data, the benefit estimates presented in this analysis should be considered incomplete.

There are several possible sets of assumptions underlying the benefits estimates in this analysis. The set of assumptions underlying the low end estimate represent a conservative approach which assumes that both human health and the environment are less responsive to changes in air pollutants. For example, the low end assumes that no health effects are associated with changes in $PM_{2.5}$ concentrations below a threshold of 15 $\mu g/m^3$. In addition, the low end assumes that reductions in NOx emissions have less positive impacts on PM air quality relative to the high end case. The high end estimate is based on a set of assumptions that represent potential benefits which would result if human health and the environment are more responsive to reduced pollution levels than estimated in the low end. In addition, the high end assumes that reductions in NOx emissions have greater positive impacts on PM air quality relative to the low end. It should be emphasized that the high and low ends of the plausible range are not the same as upper and lower bounds. For many of the quantitative assumptions involved in the analysis, credible, though less plausible, arguments could be made for an even higher or lower choice, which could lead to an even greater spread between the high end and low end estimates.

Table ES-3 lists the anticipated health and welfare benefits categories that are reasonably associated with reducing the regional transport of NOx, specifying those for which sufficient quantitative information exists to permit benefit calculations. Because of the inability to monetize some existing benefit categories, such as changes in pulmonary function and altered host defense mechanisms, some categories are not included in the calculation of the monetized benefits.

Table ES-3
Ozone, NOx, and PM Benefits from the NOx SIP Call

	Benefits of Ozone and NOx Reductions-- Reductions in:	Benefits of PM Reductions-- Reductions in:
	Quantified	
Health	Mortality (short-term exposures) Hospital admissions for all respiratory illnesses Acute respiratory symptoms	Mortality (long- and short-term exposures) Hospital admissions for: all respiratory illnesses congestive heart failure ischemic heart disease Acute and chronic bronchitis Lower and upper respiratory symptoms Minor restricted activity days Work loss days
Welfare	Commodity crop yield losses Commercial forest yield losses Worker productivity losses	Household soiling Impaired visibility Nitrogen deposition to estuarine and coastal waters
	Unquantified	
Health	Airway responsiveness Pulmonary inflammation Increased susceptibility to respiratory infection Acute inflammation and respiratory cell damage Chronic respiratory damage/Premature aging of lungs UV-B (disbenefit)	Changes in pulmonary function Morphological changes Altered host defense mechanisms Other chronic respiratory disease Cancer
Welfare	Ecosystem and vegetation effects in Class I areas (e.g., national parks) Damages to urban ornamentals (e.g.,grass, flowers, shrubs, and trees in urban areas) Fruit and vegetable crop losses Reduced yields of tree seedlings and non-commercial forests Damage to ecosystems Materials damage (other than consumer cleaning cost savings) Nitrates in drinking water Brown clouds Passive fertilization (disbenefit)	Materials damage (other than consumer cleaning cost savings) Damage to ecosystems (e.g., acid sulfate deposition) Nitrates in drinking water Brown clouds

Table ES-4 shows the range of total monetized benefits for the main health and welfare endpoint groups associated with the emissions changes that most closely approximate the NOx SIP call budget. The range of values in this table is intended to represent the plausible range of the benefits that may result from this rule after accounting for important uncertainties.

Table ES-4
Summary of Benefits in 2007 by Major Category for the
Selected Regulatory Alternative[a]
(millions of 1990 dollars)

Category	"Low" Assumption Set	"High" Assumption Set
Ozone Health and Welfare	$27	$1,353
Agriculture & Forestry	$260	$574
Nitrogen Deposition	$238	$238
PM Health and Welfare	$575	$2,005
Total	**$1,100**	**$4,170**

[a] Potential benefit categories that have not been quantified and monetized are listed in Table ES-3.

Comparison of Costs and Monetized Benefits

Cost-benefit analysis provides a valuable framework for organizing and evaluating information on the effects of environmental programs. This benefit-cost comparison is intended to generally inform the public about the potential costs and benefits that may result when control strategies to limit NOx emissions for mitigating regional ozone transport are implemented by the States. Table ES-5 presents a comparison of monetized benefits and total annual costs for the selected alternative for setting State budgets in the NOx SIP call. From EPA's examination of five major alternatives for setting the NOx budget, there are several major conclusions that can be drawn from this RIA:

- For the "High" assumption set, monetized net benefits are positive and substantial for all regulatory alternatives.

- As modeled, Regionality 1 is an inferior alternative, i.e., even though 0.20 Trading is less stringent it achieves greater benefits at lower total costs.

- Net benefits are greatest at the most stringent regulatory alternative evaluated, i.e., 0.12 Trading. For the "High" assumption set, net benefits are approximately 33 percent higher for the 0.12 Trading relative to the 0.15 Trading alternative. For the "Low" assumption set, net benefits are positive only for the 0.12 Trading alternative.

- While net benefits are negative for the "Low" assumption set for all but the 0.12 Trading alternative, it is important to remember that while all of the costs are included, many benefit categories could not be quantified. In addition, the "Low" assumption set estimate assumes that there are no reductions in premature mortality associated with ozone reductions. Relaxing this one assumption would result in positive net benefits for all alternatives for the "Low" assumption set.

Table ES-5
Comparison of Annual Costs and Monetized Benefits in 2007 Associated with the NOx SIP Call
(millions of 1990 dollars)

Benefits Case	Total Annual Costs	Annual Monetized Benefits*	Annual Net Benefits
"Low" Assumption Set	$1,660	$1,100	($560)
"High" Assumption Set	$1,660	$4,170	$2,510

*There are many benefits of the NOx SIP call that EPA was not able to quantify or monetize.

Limitations

Comparing the benefits and the costs provides one framework for policy makers and the public to assess policy alternatives. Not all the potential costs and benefits can be captured in any analysis. However, EPA is generally able to estimate reasonably well the costs of pollution controls based on today's control technology and assess the important impacts when it has sufficient information for its analysis. EPA compiled through the OTAG process and from many other sources sufficient information for this rulemaking. There are, however, important limitations in the RIA analysis:

- EPA is increasingly able to estimate benefits from pollution controls, but EPA believes that there are many important benefits that it can not quantify or monetize that are associated with the NOx SIP call, including many health and welfare effects. There are also potential disbenefits that are not quantified, including passive nitrogen fertilization and UV-B screening.
    - EPA must employ different pollutant models to characterize the effects of alternative policies on relevant pollutants. Not all atmospheric models have been widely validated against actual ambient data. The Agency has chosen the best available models for its application needs in this RIA and tried to make the most reasonable assumptions possible in using them for predicting air quality changes.

- There are some data limitations in some aspects of the RIA, despite the Agency's extensive efforts to compile information for this rulemaking. While they exist, EPA believes that it has used the models and assumptions that are made to conduct its analysis in a reasonable way based on the available evidence, but this should be kept in mind when reviewing various aspects of the RIA's results.

- Another factor that adds to the uncertainty of the results is the potential for pollution control innovations that can occur over time It is impossible to estimate how much of an impact, if any, new technologies that are just now emerging may have in lowering the compliance costs for the NOx SIP call, which goes into effect in 2003. We can only recognize their possible influence.

- There is the uncertainty regarding future costs that exists due to the flexibility that occurs under the emissions cap-and-trade program that EPA is encouraging the States to set up. The analysis that EPA has done to date has been fairly conservative in considering the electric power industry and large industrial boilers and combustion turbines operating separately under their own trading programs. In reality, they should enter the same trading pool and there should be greater efficiency and lower costs that result.

- Qualitative and more detailed discussions of the above and other uncertainties and limitations are included in the analysis. Where information and data exists, quantitative characterizations of these uncertainties are included. However, data limitations prevent an overall quantitative estimate of the uncertainty associated with final estimates. Nevertheless, the reader should keep all of these uncertainties and limitations in mind when reviewing and interpreting the results.

- Despite the above limitations, EPA believes that the RIA provides evidence that the benefits resulting from the NOx SIP call will be up to two and one-half times the costs.

Addendum to Executive Summary

In response to comments, EPA has revised the State NOx budgets that it set for the electric power industry on the basis of .15 lbs/mmBtus in the final days of the rulemaking process. The SIP call region budget was lowered from 564 thousand tons of NOx during the ozone season to 544 thousand tons of NOx. The Agency also decided to create a "compliance supplement pool" for use in 2003 and allow banking with flow controls in the trading program that EPA is encouraging States to undertake.

For the adjustment of the NOx budget to 544 thousand tons for the electricity generating units, the Agency estimates that there will be a reduction of ozone season NOx emissions by 958 thousand tons in 2007 at an annual cost of $1,440 million. This is an average cost-effectiveness of $1,503 per ton of NOx reductions during the ozone season. The total ozone season NOx emission reductions from the NOx SIP call if the States implement the program the way EPA used to set the budget is 1,161 thousand tons.

An adjustment to the emissions inventory for the non-EGU sources was also made as a result of public comments. The reanalysis following these emission inventory adjustments indicated only minor changes in the costs. Benefit estimates are not recalculated for either adjustments to the NOx budget or emission inventory, but the conclusions drawn from the RIA are not expected to differ significantly.

Chapter 1. INTRODUCTION AND BACKGROUND

1.1 Introduction

This document presents a Regulatory Impact Analysis for the final NOx SIP call rule, which addresses regional transport issues related to ozone attainment[1]. This rule requires certain States to take action to reduce emissions of nitrogen oxides (NOx) that contribute to nonattainment of ozone standards in downwind States[2]. This RIA also satisfies the analytical requirements for the proposed NOx Federal Implementation Plan (FIP) and Clean Air Act (CAA) section 126 petition actions. The proposed FIP may be needed if any State fails to revise its SIP to comply with the final NOx SIP call. The proposed action under CAA section 126 responds to petitions filed with EPA by eight Northeastern States requesting that EPA provide relief from emissions sources in several upwind States that may be contributing to ozone nonattainment in the petitioning States[3].

The Clean Air Act (CAA) requires States to demonstrate attainment of the National Ambient Air Quality Standards (NAAQS) for ozone. Many States have found it difficult to demonstrate attainment of the ozone NAAQS due to the widespread regional transport of ozone and its precursors, NOx and volatile organic compounds (VOCs). The Ozone Transport Assessment Group (OTAG) was established in 1995 to undertake an assessment of the regional transport problem in the Eastern half of the United States. OTAG was a collaborative process among 37 affected States, the District of Columbia, the U.S. Environmental Protection Agency (EPA), and interested members of the public, including environmental groups and industry representatives.

OTAG concluded that regional reductions in NOx emissions are needed to reduce the transport of ozone and its precursors. OTAG recommended that major sources of NOx emissions (utility and other stationary sources) be controlled under State NOx budgets, and also recommended development of an emissions trading program.

After a review of OTAG's analysis, findings, and recommendations, EPA proposed a rule to limit summer season NOx emissions in a group of States that the Agency believes are significant contributors to ozone in downwind areas.[4] In a November 7, 1997 Notice of Proposed Rulemaking (NPR), EPA made

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[1] This document is the second volume a two volume set. Volume 1 covers the estimated costs and economic impacts of the final NOx SIP call rule.

[2] Ground level (or tropospheric) ozone is an air pollutant that forms when its two primary components, oxides of nitrogen and volatile organic compounds , combine in the presence of certain meteorological conditions. Ozone is associated with a variety of adverse effects both to human health and to the environment. For more information on these adverse effects refer to Chapter 4 of this RIA.

[3] Unless necessary to provide specific emphasis, the term "NOx SIP call" will be used (rather than "FIP" or "section 126 petitions") throughout this report when referring to the regulatory framework that is analyzed and reported in this RIA. See section 1.4 for additional detail on the analytical relationship between these three regulatory actions.

[4] NOx emissions reductions were proposed for 22 States and the District of Columbia.

a determination that transport of ozone from certain States in the OTAG region[5] makes a significant contribution to nonattainment, or interferes with the maintenance of attainment, with the ozone NAAQS in downwind States (FR 1997a). EPA proposed a summer season NOx budget (in tons of NOx) for each of these States. These States will be required to amend their State Implementation Plans (SIPs) through a call-in procedure established in Section 110 of the Clean Air Act Amendments of 1990 (CAAA). In a May 1998 Supplemental Notice of Proposed Rulemaking (SNPR), EPA made technical corrections to the State NOx budgets, and developed a proposed trading rule to provide for emissions trading (FR 1998a). The SNPR also included an analysis of the air quality impacts of the proposed rule. The State NOx emissions budgets, trading rule, and related provisions are now being promulgated as a final rule.

A technical background support document prepared for the November 7, 1997 NPR estimated costs and emissions reductions associated with an assumed strategy that States might take to achieving the proposed budgets (EPA, 1997a). These analyses were updated to reflect technical corrections to the population of sources and growth estimates on which the State-specific budgets were based and assess the effects of the proposed trading system, in an analysis supporting the April 1998 SNPR (EPA 1998a).

This document provides the supporting Regulatory Impact Analysis (RIA) for the final rule. This analysis expands and updates the previous analyses, to reflect the provisions of the final rule and to provide analysis of the potential benefits and economic impacts as well as the costs, emissions reductions and air quality impacts associated with the rule.

The remaining sections of this chapter address the following topics:

1.2 Relevant requirements of the Clean Air Act;

1.3 Overview of the NOx SIP call rulemaking;

1.4 Relationship between the NOx SIP call, FIP, and section 126 actions;

1.5 Statement of need for the NOx SIP call;

1.6 Administrative requirements addressed by this RIA;

1.7 Structure of the RIA and organization of this document; and

1.8 References for Chapter 1.

1.2 The Clean Air Act

The 1970 Clean Air Act Amendments required EPA to issue, periodically review, and, if necessary, revise, NAAQS for ubiquitous air pollutants (Sections 108 and 109). States are required to submit SIPs to attain those NAAQS, and Section 110 of the CAA lists minimum requirements that SIPs must meet. Congress anticipated that all areas would attain the NAAQS by 1975. In 1977, the CAA was amended to provide additional time for areas to reach the NAAQS and included the requirement that

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[5] The OTAG region consists of 37 States east of 104° W longitude.

States reach the NAAQS for ozone by 1982 or 1987. In addition, the 1977 amendments included provisions that required SIPs to consider adverse downwind effects and allowed downwind States to petition for tighter controls on upwind States that contribute to their NAAQS nonattainment status.

In 1990, the Clean Air Act was again amended . This section outlines requirements of the 1990 Clean Air Act Amendments (CAAA) related to NOx reductions and the NOx SIP call. The discussion includes the ozone and NOx requirements and a review of the guidelines for new or advanced air emissions
control technologies.

1.2.1 Ozone Requirements

The CAAA included provisions designed to address the continued nonattainment of the existing ozone NAAQS, specified requirements that would apply if EPA revised the existing standard, and addressed transport of air pollutants across State boundaries.

In 1991 and 1992, areas not in attainment with the 1-hour ozone NAAQS were placed in one of five classifications, based on the degree of nonattainment. Requirements for moving toward attainment, including definitions of "major source" for VOCs and NOx, attainment dates and new source offset ratios, were established for each of the five classifications. Within an area known as the Northeast Ozone Transport Region (OTR), all sources emitting 50 tons or more of ozone forming pollutants a year are defined as "major sources," regardless of their current attainment classification. Certain emissions limits apply to major sources, and even more stringent requirements apply for new major sources in nonattainment areas.

Since passage of the 1990 CAAA, EPA has revised the NAAQS for ozone. EPA is required to review the NAAQS at least every five years to determine whether, based on new research, revisions to the standards are necessary to continue to protect human health and the environment. As a result of the most recent review, EPA revised the NAAQS for both particulate matter and ozone. The previous ambient air quality standard for ozone was 0.12 ppm based on 1-hour averaging of monitoring results. The revised standard was set at 0.08 ppm based on an 8- hour averaging period. The 1-hr standard remains in effect until EPA determines that a given area has air quality meeting its 1-hour standard. This is necessary to ensure continued progress in those areas and a smooth transition between the two standards.

On July 16, 1997, President Clinton issued a directive to EPA on the implementation strategy for the new ozone and particulate NAAQS. The goal of the implementation strategy is to provide flexible, common-sense, and cost-effective means for communities and businesses to comply with the new standard. The EPA has issued proposed guidance for public comment on implementation of the revised standards (August 24, 1998, 63 FR 45060). Additional guidance will be proposed in October 1998. The August and October guidance will be combined and issued as one document in December 1998. The implementation strategy includes:

> *Endorsement of a Regional Approach*: Citing EPA's work with the OTAG, the implementation strategy notes that ozone needs to be addressed as a regional problem. The Directive indicates that, based on OTAG recommendations, EPA will propose a rule to provide a flexible, common-sense, and cost effective means for communities and businesses to comply with the new

standards. The strategy states that EPA will encourage and assist the States to develop a regional emissions cap-and-trade system, modeled on the current acid rain program, as a way to achieve reduction in NOx emissions at lower cost.

Transitional Classifications: Areas that attain the 1-hour standard but that do not attain the new 8-hour standard will be eligible for a specific "transitional" classification, if they participate in a regional strategy and/or submit early plans addressing the new standard. EPA will revise its rules for new source review (NSR) and conformity so that States will be able to comply with the new standards with only minor revisions to the existing programs in such transitional areas. Areas which will achieve attainment as a result of the regional strategy need not implement any additional local controls. Areas that will not achieve the 8-hour standard even with the regional strategy are eligible for transitional status if they submit revised SIPs in the year 2000 demonstrating attainment of the 8-hour standard on the same schedule as the regional transport requirements.

Cost-Effective Implementation Strategies: EPA will encourage States to design strategies for both the PM and ozone standards that focus on getting low cost reductions and that limit the cost of control to under $10,000 per ton for all sources. EPA will encourage market-based strategies to lower the cost of attainment and stimulate technology innovation.

The NOx SIP call, therefore, plays an important role in the implementation strategy for the new ozone NAAQS, by instituting a regional strategy that will encourage cost-effective attainment of the new standard.

1.2.2 NOx Control and Ozone Reduction

To address the CAAA provisions regarding continued nonattainment of the existing ozone NAAQS, EPA's post-1994 attainment strategy guidance for the 1-hour ozone standard called for continued emissions reductions within ozone nonattainment areas together with a national assessment of the ozone transport phenomenon. Recognizing that no individual state or jurisdiction can effectively assess or resolve all of the issues relevant to ozone transport, the Environmental Council of States (ECOS) formed a national work group to address ozone pollution.[6] OTAG was established to assist states east of the Mississippi River to attain federal ozone standards and to develop regional strategies to address regional transport problems.[7] The multi-state, multi-stakeholder OTAG process included input from State and local governments, industry, environmental groups, and the Federal government. The stated goal of OTAG was to:

> Identify and recommend a strategy to reduce transported ozone and its precursors which, in combination with other measures, will enable attainment and maintenance of the national ambient ozone standard in the OTAG region. A number of criteria will be used to select the

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[6] ECOS is a national organization of environmental commissioners with members from the 50 States and territories.

[7] Information on OTAG and copies of documents produces by the group can be accessed on-line at http://www.epa.gov/ttn/otag.

strategy including, but not limited to, cost effectiveness, feasibility, and impacts on ozone levels (OTAG, 1995).

OTAG's work included development of a comprehensive base-year (1990) emissions inventory for use in all OTAG analyses. The inventory contained information provided by the States and reviewed by OTAG for point, area, and mobile sources. State-specific growth factors were used to project emissions for the years 1999 and 2007, which represent the CAAA attainment dates for certain nonattainment areas. Baseline 2007 emissions were also adjusted to reflect the effect of various controls required under existing regulatory programs or expected from future programs.

OTAG then conducted modeling of NOx and ozone across the OTAG region for several scenarios using geographic and atmospheric models:

Strategy Modeling. OTAG Strategy Modeling was done in several phases, and included analysis of more than 25 emission control strategies. OTAG found that domain wide emissions of NOx in the 2007 baseline are approximately 12 percent lower than 1990 and emissions of VOC are approximately 20 percent lower. Thus, existing CAA programs are expected to produce a reduction in ozone concentrations in many nonattainment areas. However, the analysis showed that some areas currently in nonattainment will likely remain so in the future and that new 8-hour nonattainment and/or maintenance problem areas may develop as a result of economic growth in some areas.

Geographic Modeling. OTAG conducted geographic modeling to isolate the effects of NOx reductions on specific subregions. Among other results, OTAG found that a regional strategy focusing on NOx reductions across a broad portion of the region will help mitigate the ozone problem in many areas of the East. Further, a regional NOx emissions reduction strategy coupled with local NOx and/or VOC reductions may be needed to achieve attainment and maintenance of the NAAQS in the region.

This analyses conducted by OTAG (OTAG 1997), as well as EPA's analyses in support of the new ozone NAAQS (EPA 1997b), showed the important role that reducing NOx emissions plays in the reduction of ozone levels. The extensive air quality modeling performed by OTAG indicated that both ozone and NOx can be transported long distances, up to 500 miles. While reductions in either NOx and VOCs may reduce ozone in localized urban areas, only NOx reductions would result in lower ozone levels across the region. The OTAG analyses showed a correlation between the magnitude and location of NOx reductions and the magnitude of reductions in ozone levels in downwind areas. OTAG, therefore, reached the following conclusion:

> Regional NOx reductions are effective in producing ozone benefits; the more NOx reduced, the greater the benefit. Ozone benefits are greatest where emission reductions are made and diminish with distance. Elevated and low level NOx reductions are both effective (OTAG 1997, pp. 51-52).

Based on the evidence of the relationship between NOx emissions and regional ozone levels, OTAG recommended that a range of NOx controls be applied in certain areas of the OTAG region. A wide variety of sources are responsible for NOx emissions, including electricity generating units, other (non-utility) stationary sources, area sources, non-road mobile sources, and highway vehicle sources. OTAG did not suggest any one "right" approach to reducing major source NOx emissions. However, OTAG developed a number of specific recommendations for EPA pertinent to the NOx SIP call, including the following:[8]

- OTAG-related controls should be implemented in the "fine grid" states.[9]
- The range of utility NOx controls should fall between Clean Air Act controls and the less stringent of 85% reduction from the 1990 rate (lb/mmBtu) or 0.15 lbs. of NOx /mmBtu summer heat input.
- The stringency of controls for individual large non-utility point sources should be established in a manner equitably with utility controls, and RACT should be considered for individual medium non-utility point sources where appropriate.[10] OTAG recommended that EPA calculate statewide NOx tonnage budgets based on a specified relationship between control levels for coal-fired power plants and control targets (emission reduction percentages) for large and medium non-utility point sources.
- OTAG stated that market-based approaches are recognized as having a number of benefits in relation to traditional command and control regulations, and that States have the option to select market systems that best suit their needs. They described two basic approaches that States might use to implement NOx emissions market systems, and recommended that a joint State/EPA Workgroup be formed to develop design features and implementation provisions for market systems that could be selected by the States.

OTAG also made recommendations that EPA develop and adopt a variety of specific national regulations that were assumed for the modeling to result in reduced emissions of VOCs and/or NOx, and to reach closure on the Tier 2 Motor Vehicle Study.

The recommendations resulting from the extensive analysis and air quality modeling conducted by OTAG have played a major role in the design of the NOx SIP call.

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[8] Summaries of the OTAG findings and recommendations are provided in OTAG 1997.

[9] The fine grid states include those modeled using UAM-V at a grid resolution of 12 km^2. All other areas constitute the coarse grid which is modeled at a grid resolution of 36 km^2. Coarse grid states are Florida, Louisiana, Texas, Arkansas, Oklahoma, Kansas, Nebraska, North Dakota, South Dakota, and Minnesota.

[10] OTAG provided specific definitions of large and medium point sources, for purposes of their recommendations.

1.2.3 Title IV NOx Requirements

Title IV of the CAAA requires annual reductions in NOx emissions. The Acid Rain NOx Program under Title IV incorporates a two-phased strategy to reduce NOx emissions. In the first phase, starting January 1, 1996, some Group 1 boilers (i.e., dry bottom wall-fired boilers and tangentially fired boilers) are required to comply with specific NOx emission limitations.[11] In the second phase, starting January 1, 2000, the remaining Group 1 boilers must comply with more stringent NOx emission limits.[12] Further, Group 2 boilers (i.e., wet bottom wall-fired boilers, cyclones, boilers using cell-burner technology, and vertically fired boilers) must comply with recently established emission limits.[13]

Compliance results for 1996 show that, from 1990 to 1996, the Phase I affected population's average NOx emission rate declined by 40 percent. Overall NOx emission reductions between 1990 and 1996 for the affected boilers totaled about 340,000 tons, i.e. a reduction of 33 percent (EPA, 1997c). In Phase II , about 1.17 million tons per year of NOx reductions are projected to result from the Acid Rain NOx Program requirements (EPA, 1996).

In developing State budgets for the NOx SIP call, EPA considered the NOx reductions committed to by Title IV NOx Program requirements.

1.2.4 New Source Performance Standards

The EPA is under court order to promulgate a new source performance standard (NSPS) on fossil-fuel-fired utility and industrial boilers in September 1998, and subpart GG of Part 60 regulates NOx emissions from combustion turbines. The final standards revise the NOx emission limits for steam generating units in subpart Da (Electric Utility Steam Generating Units) and subpart Db (Industrial-Commercial-Institutional Steam Generating Units). Only those electricity generating units and industrial steam generating units for which construction, modification, or reconstruction is commenced after July 9, 1997 would be affected by these revisions.

The NOx emission limit in the final rule for new subpart Da units is 201 nanograms per joule (ng/J) [1.6 lb/megawatt-hour (MWh)] gross energy output regardless of fuel type. For existing sources that become subject to subpart Da through modification or reconstruction, the NOx emission limit is 0.15 lb/million Btu heat input. For subpart Db units, the NOx emission limit being proposed is 87 ng/J (0.20 lb/million Btu) heat input from the combustion of any gaseous fuel, liquid fuel, or solid fuel; however, for low heat release rate units firing natural gas or distillate oil, the current NOx emission limit of 43 ng/J (0.10 lb/million Btu) heat input is unchanged.

In developing the State budgets for the NOx SIP call, EPA considered the potential NOx reductions attributable to this NSPS.

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[11] The affected dry-bottom wall-fired boilers must meet a limitation of 0.50 lbs of NOx per mmBtu averaged over the year, and tangentially fired boilers must achieve a limitation of 0.45 lbs of NOx per mmBtu, again averaged over the year (FR 1995).

[12] Annual averages of 0.46 lb/mmBtu for dry-bottom wall-fired boilers and 0.40 lb/mmBtu for tangentially fired boilers.

[13] The limits are 0.68 lb/mmBtu for cell burners, 0.86 lb/mmBtu for cyclones greater than 155 MWe, 0.84 lb/mmBtu for wet bottom boilers greater than 65 MWe, and 0.80 lb/mmBtu for vertically fired boilers (FR 1996a).

1.2.5 Reasonably Available Control Technology Requirements

In the 1977 amendments to the CAA Congress required that all SIPs for nonattainment areas contain reasonably available control measures (RACM) or reasonably available control technology (RACT). In the 1990 Amendments to the Act, Congress created RACT requirements specifically for ozone nonattainment areas under the 1-hour standard (see subpart 2 of part D of title I). Since 1977, EPA has defined RACT for ozone as the lowest emission limitation that a particular source is capable of meeting by the application of control technology that is reasonably available considering technological and economic feasibility. The EPA historically has interpreted the RACT requirement in ozone nonattainment areas to apply independent of a State's ability to demonstrate that an area will attain the ozone standard, with certain exceptions.

In the ozone-specific RACT requirement enacted in 1990, States were required to correct all existing deficiencies in RACT rules in marginal nonattainment areas to ensure the rules were adopted consistently on a national basis. In addition, all nonattainment areas classified moderate and above were required to adopt RACT for each source category for which EPA issued a Control Techniques Guideline (CTG). Over the years, EPA has issued CTG documents to assist the States in determining RACT for VOCs. Each CTG contains information on available air pollution control techniques and provides a "presumptive norm" for RACT for a specific source category. Finally, RACT for controlling NOx was also required in certain nonattainment areas classified moderate and above.

In developing implementation guidance for the revised 8-hour NAAQS, EPA is addressing the RACM/RACT requirement under subpart 1 of part D of title I, rather than subpart 2. The EPA has proposed implementation guidance for the revised ozone NAAQS which addresses several issues, including RACM/RACT. The proposed policy states that "For the 8-hour ozone NAAQS, if the [nonattainment] area is able to demonstrate attainment of the standard as expeditiously as practicable with emission control measures in the SIP, then RACM/RACT will be met and additional measures would not be required as being reasonably available." (August 24, 1998, 63 FR 45060) The policy will be finalized by December 31, 1998.

1.2.6 Northeast Ozone Transport Region

Section 184 of the CAAA delineated a multi state ozone transport region (OTR) in the Northeast and required specific additional NOx and VOC controls for all areas in this region (not only nonattainment areas). Section 184 also established the Ozone Transport Commission (OTC) for the purpose of assessing the degree of ozone transport in the OTR and recommending strategies to mitigate the interstate transport of pollution. The OTR consists of the States of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, parts of northern Virginia, and the District of Columbia. The OTC was first convened in 1991, and began analysis and evaluation of ozone reduction strategies for the region. They concluded that regional reductions of NOx emissions are particularly important in reducing ozone. The OTR States confirmed that they would implement RACT on major stationary sources of NOx, and agreed to a phased approach for additional controls, beyond RACT, for power plants and other large fuel combustion sources.

This agreement, known as the OTC Memorandum of Understanding (MOU) for stationary source NOx controls was approved on September 27, 1994. All OTC States, except Virginia, are signatories to the OTC NOx MOU. The OTC NOx MOU establishes an emissions trading system to reduce the costs of compliance with the control requirements.

In developing State budgets for the NOx SIP call, EPA considered the NOx reductions committed to by the OTR states in the OTC NOx MOU, along with the OTAG recommendations discussed above.

1.3 Overview of the NOx SIP Call Rulemaking

EPA relied extensively on the OTAG analyses and recommendations in developing the NOx SIP call. As recommended by OTAG, the rule establishes ozone season[14] NOx emission budgets for 22 States and the District of Columbia.[15] The 23 jurisdictions will be required to amend their SIPs by the year 2000, to allocate emissions control requirements among sources and to develop compliance programs for each affected source category to ensure that the NOx budget is met. These compliance programs should include: necessary pollution control measures; monitoring, reporting, and accounting procedures to ensure source emissions are not exceeding the State's NOx budget; and enforcement requirements.

Consistent with OTAG's recommendation that NOx emissions reductions be achieved primarily from large stationary sources in a trading program, EPA is encouraging States to consider additional controls on electricity generating units and other large stationary sources as a strategy for meeting statewide budgets. State budgets were developed using assumptions consistent with such a strategy. The budget for each State was developed for components of major source categories. For non-road and highway vehicle sources, budgets are based on estimates of the effectiveness in each State of national measures that EPA is taking to control emissions from mobile sources. For electricity generating units and other stationary sources, the budgets are based on applying further reasonable controls. A major factor in determining controls is the cost-effectiveness of control measures.

EPA also followed OTAG's recommendation in urging States to consider implementing market based systems to reduce the costs of complying with the new limits on NOx emissions. EPA is encouraging the States and the District of Columbia to join a trading program administrated by EPA, which is reflected in a model NOx Budget Trading Rule. This trading system would place a collective cap on NOx emissions from electricity generating units and other large boilers and combustion turbines, and provide for trading of allowances similar to the CAAA Title IV SO_2 Allowance Trading Program already in place.

Chapter 2 of Volume 1 of this report describes a number of regulatory alternatives that EPA considered in the development of this final rule. Chapter 2 of Volume 2 describes the regulatory

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[14] The ozone season for this rule is the period May 1 - September 30.

[15] The States covered by the rule include: Alabama, Connecticut, Delaware, Georgia, Illinois, Indiana, Kentucky, Maryland, Massachusetts, Michigan, Missouri, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Rhode Island, South Carolina, Tennessee, Virginia, West Virginia, and Wisconsin.

alternatives that EPA used to model air quality effects for the purpose of estimating benefits of the final rule.

1.4 Relationship Between NOx SIP Call, FIP, and Section 126 Petitions

In conjunction with promulgating the NOx SIP call, EPA has begun efforts to respond to petitions filed by eight northeastern States (FR 1998b). These petitions were filed under section 126 of the CAA, which authorizes States to petition EPA to address air pollution transported from upwind States. The petitions request that EPA make a finding that NOx emissions from certain major stationary sources significantly contribute to ozone nonattainment problems in the petitioning States. If EPA makes such a finding, the Agency would be authorized to establish Federal emissions limits for these sources. The petitions recommend control levels for EPA to consider. In an April 30, 1998 Advanced Notice of Proposed Rulemaking (ANPR) (63 FR 24058), EPA presented a schedule for taking actions on the petitions, made a preliminary identification of upwind sources that may significantly contribute to 1-hour and 8-hour ozone nonattainment problems in the petitioning States (using information developed for the NOx SIP call NPR), and requested comment on legal and policy issues raised by section 126 of the CAA. In responding to the section 126 petitions, EPA intends to be consistent with the approaches taken in the NOx SIP call.

At the same time that EPA promulgates the NOx SIP call rule, EPA is proposing NOx Federal Implementation Plans (FIPs) that may be needed if any State fails to comply with the final NOx SIP call rule. The FIP requirements are intended to be consistent with the approaches taken in the final NOx SIP call, including a proposed federal NOx Budget Trading Program for electric utility sources and other large industrial boilers and combustion turbines.

Since the final NOx SIP call and the proposed FIP and section 126 petition actions are generally consistent in the manner in which they assess affected emissions sources, EPA is preparing only a single RIA for all three actions. Even though the facts of the analysis contained in this report do not differ significantly for any of the three actions, the results have slightly different interpretations. In the case of the final NOx SIP call, the results in this report are illustrative of potential benefits that may result from the SIP call. The NOx SIP call itself does not directly impose regulatory requirements on emissions sources. Instead, the SIP call requires States to develop strategies to meet the State NOx budgets contained in the final NOx SIP call rule. States have discretion on which emissions sources to control to realize the required reductions.

However, the FIPs, if needed, and the section 126 petition responses will directly impose regulatory requirements on emissions sources. EPA is proposing to regulate sources under the FIP and section 126 petition actions with strategies that are modeled in this RIA. In these cases the results presented in the RIA reflect potential outcomes from direct federal regulation, and, depending on the outcome of the final actions, have a higher probability of reflecting the actual outcome of the rules.

The proposed section 126 actions will potentially affect only a subset of the sources potentially affected by the broader NOx SIP call. Sources in Georgia, South Carolina, and Wisconsin are not affected by the proposed section 126 rule. Therefore, the benefits associated with the proposed section 126 rule are likely to be smaller than for the final NOx SIP call. Since Georgia, South Carolina, and Wisconsin are affected under the final NOx SIP call, and would be subject to a final FIP if they fail to comply with the provisions of the final NOx SIP call, EPA did not see the need to separately address the potentially smaller benefits for the proposed section 126 rule.

1.5 Statement of Need for the NOx SIP Call

The following sections discuss the statutory authority and legislative requirements of the NOx SIP call, health and welfare effects of NOx emissions, and the basis for the regulatory actions of the NOx SIP call.

1.5.1 Statutory Authority and Legislative Requirements

Section 110(a)(2)(D) provides that a SIP must contain provisions preventing its sources from contributing significantly to nonattainment or interfering with maintenance of the NAAQS in a downwind State. This section applies to all pollutants covered by NAAQS and all areas regardless of their attainment designation. Section 110(k)(5) authorizes EPA to find that a SIP is substantially inadequate to meet any CAA requirement, as well as being inadequate to mitigate interstate transport as described in Sections 184 and 176A. Such a finding would require States to submit a SIP revision to correct the inadequacy within a specified period of time.

1.5.2 Health and Welfare Effects of NOx Emissions[16]

NOx emissions contribute to the formation of ozone during the summer season. Ozone is a major component of smog and is harmful to both human health and the environment. Research has shown the following health effects of ozone:

- Exposure to ambient ozone concentrations has been linked to increased hospital admissions for respiratory ailments, such as asthma. Repeated exposure to ozone can make people more susceptible to respiratory infection and lung inflammation, and can aggravate preexisting respiratory diseases.

- Children are at risk for the effects of ozone because they are active outside during the summer months when ozone levels are at their highest. Adults who are outdoors and moderately active during the summer months are also at risk. These individuals can experience a reduction in lung function and increased respiratory symptoms, such as chest pain and cough, when exposed to relatively low ozone levels during periods of moderate exertion.

- Long-term exposures to ozone can cause repeated inflammation of the lung, impairment of lung defense mechanisms, and irreversible changes in lung structure, which could lead to premature aging of the lungs and/or chronic respiratory illnesses such as emphysema and chronic bronchitis.

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[16] A comprehensive discussion of health and environmental issues related to NOx appears in EPA, 1997d.

- Several peer reviewed epidemiology studies recently published suggest a possible association between ozone exposure and mortality, though several other studies find no significant association.

Ozone has also been shown to adversely affect vegetation, including reductions in agricultural and commercial forest yields, reduced growth and decreased survivability of tree seedlings, and increased tree and plant susceptibility to disease, pests and other environmental stresses.

NOx emissions also contribute to fine particle matter formation (PM). Exposure to airborne PM has a wide range of adverse health effects. The key health effects associated with PM include: 1) premature mortality; 2) aggravation of respiratory and cardiovascular disease (as indicated by increased hospital admissions and emergency room visits, school absences, work loss days, and restricted activity days); 3) changes in lung function and increased respiratory symptoms; 4) changes to lung tissues and structure; 5) altered respiratory defense mechanisms; and 6) chronic bronchitis. Most of these effects have been consistently associated with ambient PM concentrations, which have been used as a measure of population exposure, in a number of community epidemiological studies. Although mechanisms by which particles cause effects have not been elucidated, there is general agreement that the cardio-respiratory system is the major target of PM effects. Particulate matter also is associated with welfare effects, which include visibility impairment, soiling, and materials damage.

Based on its review of the scientific evidence, EPA established standards for $PM_{2.5}$ and retained the standards for PM_{10}. The EPA revised the secondary (welfare-based) PM NAAQS by making them identical to the primary standards.

Finally, NOx emissions contribute to a wide range of health and environmental problems independent of their contribution to ozone or PM formation. Among these problems are acid deposition, nitrates in the drinking water, and nutrient loading in waterways, particularly in sensitive coastal estuaries where air deposition is a major portion of nitrogen loadings.

1.5.3 Need for Regulatory Action

The existing and revised ambient air quality standards for ozone set levels necessary for the protection of human health and the environment. Under the CAA, attainment of these standards depends on the implementation of State-specific pollution control strategies contained in SIPs to reduce NOx and volatile organic compound emissions, in conjunction with EPA promulgation of national controls for some sources of pollution.

It is clear that, even with planned national measures in place, several States cannot bring existing nonattainment areas into compliance with the current ozone standard, or avoid the application of very costly local control measures, unless the transport of ozone from other upwind areas is reduced. Furthermore, many States will find it hard, if not impossible, to avoid nonattainment with the revised ozone NAAQS, or come into attainment with it in the future, unless mitigation of the ozone transport problem occurs. This dilemma has raised concerns over the fairness of downwind areas having to cope with the pollution coming from areas upwind. The current regulatory framework requires States to develop SIPs that demonstrate air quality improvements sufficient to reach specific attainment levels. States have no control over neighboring States' actions, and may be unable to meet their air quality goals due to pollutants transported across State lines. The contribution of upwind sources outside of nonattainment areas creates a dilemma for States seeking to reach air quality goals.

States could develop local ozone mitigation strategies to address the impact of transported ozone. However, local efforts could lead to undesirable outcomes. Some States might develop SIPs that do not achieve compliance in some serious and severe ozone nonattainment areas, because the States would deem local measures needed to achieve attainment as too draconian.

The NOx SIP call is designed to mitigate these problems through a coordinated Federal and State effort to address regional ozone transport. This rule will create a more effective, efficient and equitable approach for EPA and the States to promote attainment with the current and new ozone NAAQS.

1.6 Requirements for this Regulatory Impact Analysis

This section describes various legislative and executive requirements that govern the analytical requirements for Federal rulemakings, and describes how each analytical requirement is addressed in this RIA.

1.6.1 Executive Order 12866

Executive Order 12866, "Regulatory Planning and Review" (FR, 1993), requires EPA to provide the Office of Information and Regulatory Affairs of the Office of Management and Budget with an assessment of the costs and benefits of significant regulatory actions. A "significant regulatory action" is defined as "any regulatory action that is likely to result in a rule that may:

- Have an annual effect on the economy of $100 million or more or adversely affect in a material way the economy, a sector of the economy, productivity, competition, jobs, the environment, public health or safety, or State, local, or tribal governments or communities;
- Create a serious inconsistency or otherwise interfere with an action taken or planned by another agency;
- Materially alter the budgetary impact of entitlements, grants, user fees, or loan programs or the rights and obligations of recipients thereof; or
- Raise novel legal or policy issues arising out of legal mandates, the President's priorities, or the principles set forth in the Executive Order" (FR, 1993).

For any such regulatory action, the Agency must provide a statement of the need for the proposed action, must examine alternative approaches, and must estimate social benefits and costs.

EPA has determined that the NOx SIP call is a significant regulatory action because its effect on the economy is expected to exceed $100 million per year. This volume of the RIA provides the benefits information required by E.O. 12866 for a significant regulatory action; Volume 1 fulfills the associated cost and economic impact requirements.

1.6.2 Regulatory Flexibility Act and Small Business Regulatory Enforcement Fairness Act of 1996

The Regulatory Flexibility Act (RFA) of 1980 (PL 96-354) requires that agencies conduct a screening analysis to determine whether a regulation will have a significant impact on a substantial number of small entities, including small businesses, governments and organizations. If a regulation will have such an impact, agencies must prepare a Regulatory Flexibility Analysis, and comply with a number of procedural requirements to solicit and consider flexible regulatory options that minimize adverse economic impacts on small entities. The RFA's analytical and procedural requirements were strengthened by the Small Business Regulatory Enforcement Fairness Act (SBREFA) of 1996.

For reasons explained more fully in the Federal Register notice for the final NOx SIP call, it is EPA's position that the RFA as amended by SBREFA does not apply to the final NOx SIP call, because the rule does not impose direct requirements on emissions sources. States will ultimately decide what emissions limits are imposed for specific sources. However, the EPA has determined that the RFA as amended by SBREFA does apply to both the proposed FIP and section 126 actions. Therefore, EPA has examined the potential for small entity impacts to provide policy makers and States with additional decision information.

The RFA and SBREFA require use of definitions of "small entities", including small businesses, governments and non-profits, published by the Small Business Administration (SBA).[17] Screening analyses of economic impacts presented in Volume 1 of the RIA examine potential impacts on small entities.

1.6.3 Unfunded Mandates Reform Act

The Unfunded Mandates Reform Act (UMRA) of 1995 (PL 104-4) was enacted to focus attention on federal mandates that require other governments and private parties to expend resources without federal funding, to ensure that Congress considers those costs before imposing mandates, and to encourage federal financial assistance for intergovernmental mandates. The Act establishes a number of procedural requirements. The Congressional Budget Office is required to inform Congressional committees about the presence of federal mandates in legislation, and must estimate the total direct costs of mandates in a bill in any of the first five years of a mandate, if the total exceeds $50 million for intergovernmental mandates and $100 million for private-sector mandates.

Section 202 of UMRA directs agencies to provide a qualitative and quantitative assessment of the anticipated costs and benefits of a Federal mandate that results in annual expenditures of $100 million or more. The assessment should include costs and benefits to State, local, and tribal governments and the private sector, and identify any disproportionate budgetary impacts. Section 205 of the Act requires agencies to identify and consider alternatives, including the least costly, most cost-effective, or least burdensome alternative that achieves the objectives of the rule.

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[17] Where appropriate, agencies can propose and justify alternative definitions of "small entity." This RIA relies on the SBA definitions.

EPA has not reached a final conclusion as to the applicability of the requirements of UMRA to the NOx SIP call rule. EPA has determined that UMRA does affirmatively apply to both the proposed FIP and proposed section 126 rules. Volume 1of this RIA presents a summary of analyses of the potential impacts of the NOx SIP call on State and local governments, to support compliance with section 202 of UMRA. This analysis includes administrative requirements of State and local governments associated with revising SIPs and collecting and reporting data to EPA. It also includes the compliance and administrative costs to emissions sources owned by government entities. In addition, EPA has prepared a more detailed written statement consistent with the requirements of section 202 and section 205of the UMRA and placed that statement in the docket for this rulemaking.

1.6.4 Paperwork Reduction Act

The Paperwork Reduction Act of 1995 (PRA) requires Federal agencies to be responsible and publicly accountable for reducing the burden of Federal paperwork on the public. EPA has submitted an Information Collection Request (ICR) to the Office of Management and Budget (OMB) in compliance with the PRA. The ICR explains the need for additional information collection requirements and provides respondent burden estimates for additional paperwork requirements to State and local governments associated with the NOx SIP call.

1.6.5 Executive Order 12898

Executive Order 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations," requires federal agencies to consider the impact of programs, policies, and activities on minority populations and low-income populations. Disproportionate adverse impacts on these populations should be avoided. According to EPA guidance, agencies are to assess whether minority or low-income populations face risk or a rate of exposure to hazards that is significant (as defined by the National Environmental Policy Act) and that "appreciably exceeds or is likely to appreciably exceed the risk or rate to the general population or other appropriate comparison group." (EPA, 1996b) This guidance outlines EPA's Environmental Justice Strategy and discusses environmental justice issues, concerns, and goals identified by EPA and environmental justice advocates in relation to regulatory actions.

The NOx SIP call is expected to provide health and welfare benefits to eastern U.S. populations, regardless of race or income. Chapter 3 of this RIA presents information on the changes in potential ozone and PM exposure for white and non-white populations and low income populations, and compares these relative changes to the general populations.

1.6.6 Health Risks for Children

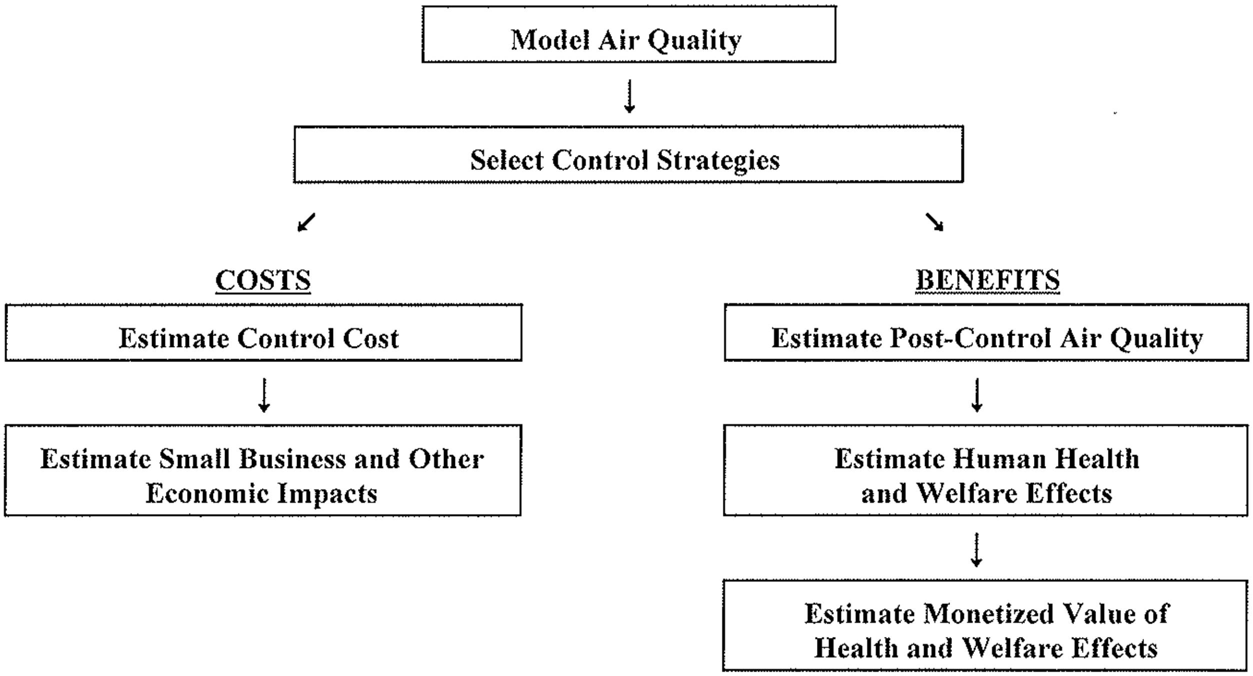
Executive Order 13045, "Protection of Children from Environmental Health Risks and Safety Risks," directs Federal agencies developing health and safety standards to include an evaluation of the health and safety effects of the regulations on children. Regulatory actions covered under the Executive Order include rulemakings that are economically significant under Executive Order 12866, and that concern an environmental health risk or safety risk that the agency has reason to believe may disproportionately affect children. EPA has developed internal guidelines for implementing the E.O. 13045. (EPA, 1998b)

The NOx SIP call is a "significant economic action," because the annual costs are expected to exceed $100 million. Both NOx and ozone formed by NOx are known to affect the health of children and other sensitive populations, which were addressed in the development of the new ozone NAAQS. However, the NOx SIP call is not expected to have a disproportionate impact on children. Chapter 3 of this RIA presents information on the changes in potential ozone and PM exposure for persons under the age of 18.

1.7 Structure and Organization of the Regulatory Impact Analysis

The potential costs, economic impacts and benefits have been estimated for this rulemaking. The flow chart in Figure 1-1 summarizes the analytical steps taken in developing the results presented in this RIA.

Figure 1-1
Flowchart of Analytical Steps



The assessment of costs, economic impacts, and benefits consists of multiple analytical components, dependent upon emissions and air quality modeling. In order to estimate baseline air quality in the year 2007, emission inventories are developed for 1995 and then projected to 2007, based upon estimated national growth in industry earnings and other factors. Current CAAA-mandated controls (e.g., Title I reasonably available control measures, Title II mobile source controls, Title III air toxics controls, Title IV acid rain sulfur dioxide (SO_2) controls) are applied to these emissions to take account of emission reductions that should be achieved in 2007 as a result of implementation of the current PM and ozone requirements. These 2007 CAA emissions in turn are input to several air quality models that relate emission sources to area-specific pollutant concentrations. This modeled air quality is used as the base against which several alternative control options are measured and cost estimates developed. Given the estimated costs of the alternative regulatory control options, the potential economic impacts of these estimated costs on potentially affected industry sectors is subsequently analyzed. Potential health and welfare benefits are also estimated from modeled changes in air quality as a result of control strategies applied in the cost analysis. Finally, benefits and costs are compared.

The RIA analyses have been constructed such that benefits and costs are estimated incremental to those derived from the effects of implementing the CAAA in the year 2007. These analyses provide a "snapshot" of potential benefits and costs of this rulemaking in the context of implementation of CAA requirements between now and 2007 and the air quality effects that derive from economic and population growth.

States have discretion in how they achieve their NOx budgets, and different States may choose different strategies. The RIA must, therefore, be based on assumptions about how the States will choose to implement the NOx SIP call requirements. Consistent with EPA's recommendation that States focus on major stationary sources, this RIA assumes that States impose additional controls — incremental to those already required by other national programs that address NOx emissions — only for major stationary sources, and that States implement the cap-and-trade system for electricity generating units and industrial boiler and turbine sources. This assumption is illustrative of one cost-effective approach States could take to meeting the NOx SIP call budgets. States may choose different allocations of controls across major stationary sources than assumed here, or may choose to impose additional controls on area or mobile sources as well. Costs and economic impacts would differ from those estimated in this RIA to the extent that States' compliance strategies differ from the RIA assumptions.

Analysis of costs, changes in emissions, and economic impacts is conducted separately for two groups of sources: electricity generating units and other stationary sources. The Integrated Planning Model (IPM) allows analysis of trading and industry-level adjustments for electricity generating unit sources. Other stationary sources are analyzed separately, using assumptions about baseline conditions and control costs that are generally consistent with the IPM modeling assumptions used for electricity generating units.

Predicted changes in emissions due to the additional controls for electricity generating units and other stationary sources are then combined to estimate changes in air quality and to calculate the benefits of the NOx SIP call. The estimation of benefits from environmental regulations poses special challenges. These include the difficulty of quantifying the incidence of health, welfare, and environmental endpoints of concern, and the difficulty of assigning monetized values to these endpoints. As a result, many categories of potential benefits have not been monetized at all, and those that have been are given in ranges. Specifically, this RIA has adopted the approach of presenting a "plausible range" of monetized benefits to reflect these uncertainties by selecting alternative values for each of several key assumptions. Taken together, these alternative sets of assumptions define the range for the monetized benefits categories.

The remainder of the RIA is organized in the following chapters and appendices:

- Chapter 2 presents a discussion of the regulatory alternatives modeled for the benefits analysis of this rulemaking;
- Chapter 3 describes the methodology used to estimate baseline and post-control air quality impacts;
- Chapter 4 presents the analysis of the benefits of the rule; and
- Chapter 5 provides an integrated summary of costs and benefits, and compares costs and benefits for the NOx SIP call as a whole.

Where appropriate, each chapter includes a discussion of limitations of the analysis. A series of appendices follow Chapter 5 and provide more detailed descriptions of specific methodologies and results.

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Chapter 2. REGULATORY ALTERNATIVES AND EMISSIONS IMPACTS

This chapter explains the various regulatory alternatives considered in the benefits analyses. Section 2.1 provides background on the elements that differentiate the alternatives that were considered, and Section 2.2 provides information on the emissions impacts used to generate air quality changes for the benefits analyses.

2.1 Elements Considered in Developing Regulatory Alternatives

EPA's NOx SIP call sets summer NOx emissions budgets for eastern States that the Agency has found significantly contribute to the nonattainment by other States of the pre-existing ozone standard (1-hour) and will contribute in the future to nonattainment by other States with the revised ozone standard (8-hour). EPA relied heavily on its estimation of the NOx reductions that the electric power industry and other stationary sources could provide cost-effectively in setting the State budgets. Other factors, such as the feasibility of implementing controls in a reasonable time frame, also influenced the Agency's final decisions. To estimate the cost-effectiveness of controls for various sources, the Agency considered several ways that controls could be implemented in the SIP call region. However, States can place controls on their sources of NOx emissions differently than the approach that EPA used in the budget setting process, if they can show that control strategy will provide the same level of NOx reduction in the SIP call region.

This section describes the elements that make up the various regulatory alternatives considered for this analysis. The regulatory alternatives used in the benefits analysis (described in Section 2.2) represent various combinations of these elements. Some elements of the rule remain the same for all the options considered. Other elements are considered in varying combinations, including stringency of controls, geographic scope, affected sources and design of the trading system. For all options analyzed, the timing of regulatory requirements was also considered, as this issue is critical in terms of feasibility of compliance and attainment of both the pre-existing ant the revised ozone standard.

2.1.1 Type of Control

EPA had to decide on the types of regulatory approaches that the Agency wanted States to consider in their efforts to lower NOx emissions from various source categories. EPA used those approaches in estimating the cost-effectiveness of ozone season NOx controls at various levels for different types of sources. OTAG recommended that the Agency consider controls that allow for emissions trading, rather than traditional command-and-control regulation. OTAG's analysis of trading programs had shown that there could be considerable savings from this type of approach for the electric power industry (OTAG, 1997).

EPA also demonstrated the potential savings from a NOx emissions trading program that could result in its regulatory analysis for the proposed NOx SIP call (EPA, 1997a). That analysis showed that in 2005 a command-and-control program for the electric power industry would cost about 30 percent more than a trading program in the NOx SIP call region. For that reason, the Agency has focused heavily on developing regulatory approaches that States can use collectively that are based on allowance-based NOx emissions trading. It was also clear from OTAG analysis and EPA's own work that further savings and flexibility could be gained from allowing banking as part of a trading program. EPA's regulatory analysis over the last year has also considered banking options for inclusion in the Model Trading Rule for States (EPA, 1997b).

2.1.2 Geographic Scope

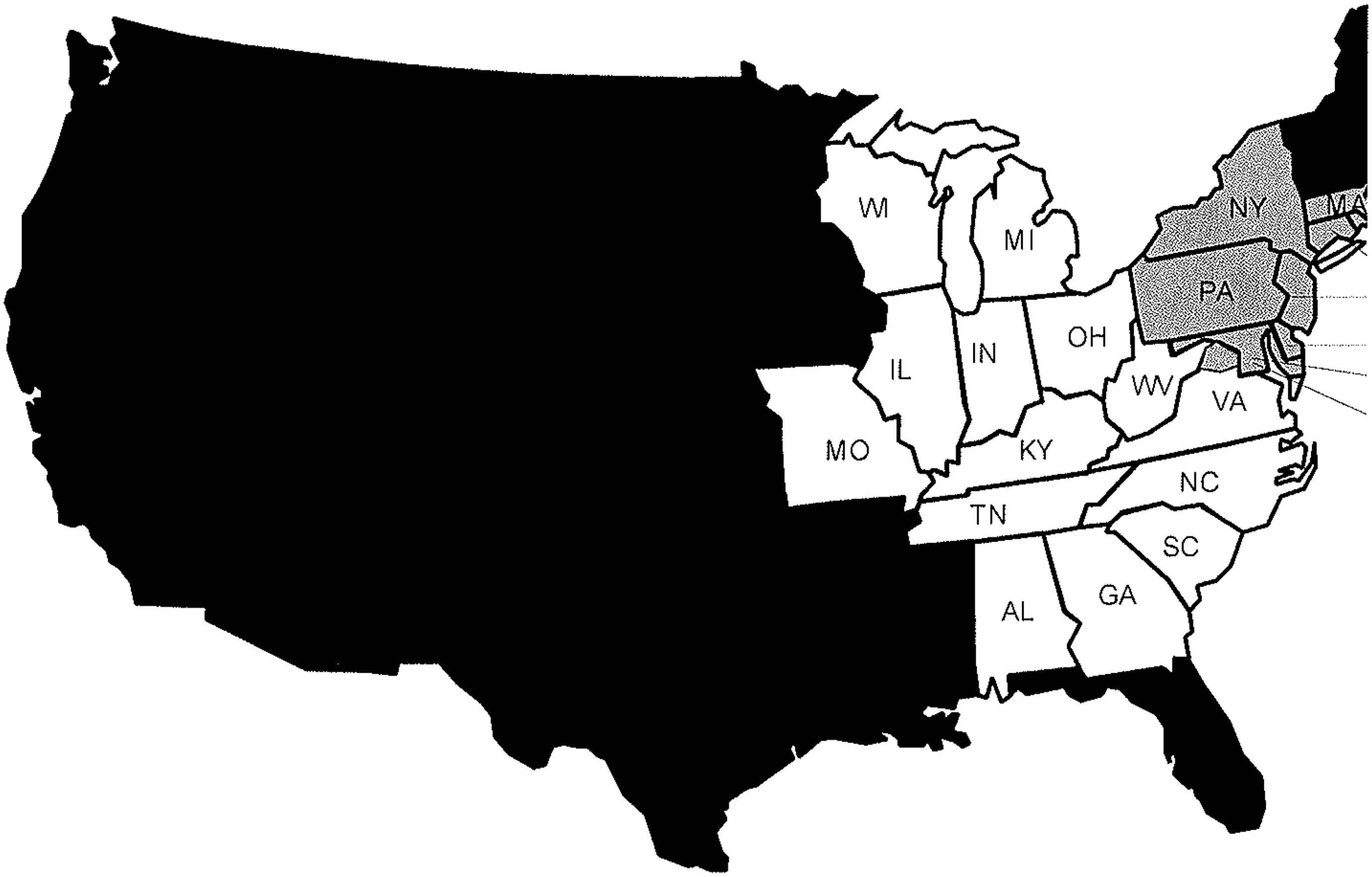
After considering OTAG's recommendations and other relevant information, EPA identified 22 States plus the District of Columbia (i.e., 23 jurisdictions) as significantly contributing to nonattainment with, or interfering with maintenance of, air quality standards in a downwind State. The SIP call region is shown in Figure 2-1 and consists of Alabama, Connecticut, Delaware, District of Columbia, Georgia, Illinois, Indiana, Kentucky, Massachusetts, Maryland, Michigan, Missouri, North Carolina, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, South Carolina, Tennessee, Virginia, West Virginia, and Wisconsin.

The final rule reflects State NOx budgets that are developed using the same region-wide stringency targets and region-wide analyses of cost-effectiveness for all 23 jurisdictions. EPA also considered dividing the SIP call region into two or three subregions in an effort to make a distinction among the States that may contribute the most to the ozone transport problem and those where the wind patterns may be less likely to affect air quality in the other States. The SIP call region was divided into two regions--Northeast and Southeast, or into three regions--Northeast, Midwest, and Southeast. Different levels of stringency are then applied in the different regions, as described below.

The two region area consists of Connecticut, Delaware, District of Columbia, Massachusetts, Maryland, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Virginia, and West Virginia in the Northeast; and Alabama, Georgia, Illinois, Indiana, Kentucky, Michigan, Missouri, North Carolina, South Carolina, Tennessee, and Wisconsin in the Southeast.

The three region area consists of Connecticut, Delaware, District of Columbia, Maryland, Massachusetts, New Jersey, New York, Pennsylvania, and Rhode Island in the Northeast; Illinois, Indiana, Kentucky, Michigan, Missouri, Ohio, Virginia, West Virginia, and Wisconsin in the Midwest; and Alabama, Georgia, North Carolina, South Carolina, and Tennessee in the Southeast.

Figure 2-1
States Included in EPA's NOx SIP call



▨ Ozone Transport Region States in the NOx SIP Call

☐ Other States in the NOx SIP Call

2.1.3 Potentially-Affected Sources

EPA has developed State budgets based on the effects of additional controls (beyond those already required by the CAAA-related or reflected in existing SIPs) only for major stationary sources of NOx emissions. These sources include: (1) electricity generating utility boilers; (2) industrial, commercial and institutional boilers; (3) combustion turbines; (4) reciprocating internal combustion engines; (4) cement manufacturing operations; and (5) other industrial processes that emit NOx. Only existing or planned CAAA-related controls are considered in calculating budgets for other sectors (area and mobile sources) that contribute to NOx emissions. States ultimately have discretion to determine which sources to regulate to achieve the budget level.

The analyses of benefits in this RIA are based on a range of assumptions about which major stationary sources will actually be targeted for additional controls by the States in implementing the NOx SIP call. The primary assumption in this analysis is that States will allocate NOx emissions reduction requirements to the largest electricity generating utility boilers; industrial, commercial and institutional boilers; combustion turbines; cement manufacturing units; and internal combustion engines.

Large electricity generating units are defined as those generating more than 25 megawatts (MW). Large industrial boilers, combustion turbines, reciprocating internal combustion engines, and other industrial NOx sources are those capable of firing greater than 250 mmBtu/hour, or that emit greater than one ton of NOx per summer day.

2.1.4 Stringency of Control Level

In order to develop a cost-effective NOx reduction strategy as a basis for establishing State budgets, EPA considered various emission reduction levels for the affected sources for the summer ozone season defined as May 1 through September 30. For the electricity generating units (EGUs), EPA considered emissions budgets based on emission limits of 0.12 lb/mmBtu, 0.15 lb/mmBtu, 0.20 lb/mmBtu, and 0.25 lb/mmBtu.[1] For the large industrial boilers and combustion turbines, EPA considered a uniform percent emission reduction from uncontrolled projected 2007 emission levels ranging from 40 percent to 70 percent. For the remaining large nonutility sources, EPA considered source category-specific control levels corresponding to cost-effectiveness cut-offs ranging from $1,500/ton to $5,000/ton.

Taking into consideration the emission reductions and associated costs projected under each of the above scenarios, EPA identified cost-effective NOx reduction strategies. Based on the reduced emissions achieved by this strategy, EPA then established State-specific budgets for ozone season NOx emissions. Alternative budgets are calculated for the different stringency levels considered for EGUs. The details of NOx budget development can be found in the budget technical support document (EPA, 1998b).

2.1.5 Effective Dates

States subject to the NOx SIP call must submit revised SIPs by September 1999. The affected sources in the States must implement NOx controls by May 2003, and EPA will assess how each State's SIP has actually performed in 2007.

2.1.6 Emissions Budget Trading System Design

To allow for use of the most cost-effective emission reduction alternatives, an emissions budget trading program is an optional component of the NOx SIP call. Each of the States subject to the NOx SIP call are encouraged to participate in this model NOx Budget Trading Program and thereby provide a mechanism for sources to achieve cost-effective NOx reductions. The trading unit is a NOx Allowance,

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[1] Limits for each electricity generating unit are expressed as a specific NOx limit of pounds of NOx per mmBtu of summer heat input projected for 2007, the year which was the focus of OTAG's analysis (the year for which air quality modeling was done).

equal to one ton of emitted NOx. Details of the trading program are described in the Federal Register notice accompanying the final rule.

Under the NOx Budget Trading Program, each of the participating States would determine how its seasonal State trading program budget is allocated among its sources. Each source would be given a certain quantity of NOx allowances. If a source's actual NOx emissions exceed its allocated NOx allowances, the source may purchase additional allowances. Conversely, if a source's actual NOx emissions are below its allocated NOx allowances, then it may sell the additional NOx allowances. Such a program creates a competitive market for NOx allowances that encourages use of the most efficient means for reducing NOx emissions.

For purposes of this analysis, trading may occur among any of the sources within the entire SIP call region or within each of the subregions. Where subregions are developed for the SIP call region, only intra-regional (within the region) trading is allowed.

Banking would allow sources that do not use all of their NOx allowances for a given year to save them for later use. If banking is allowed, however, mechanisms such as flow controls can be put in place to limit the level of exceedance of the emissions cap. Flow controls restrict the use of the banked NOx allowances by restricting their use at certain times or within certain areas. For example, a restriction may be placed on the banked allowances that allows only a set amount to be used during a defined time period.

For this RIA, EPA analyzed a variety of trading options, and trading with banking only for the .15 trading option, where banking begins after the start of the program in 2003. Banking of "early" reductions was not modeled for the 0.15 option because earlier IPM analysis suggested that owners of electricity generating units would want to use it to a very limited degree to lower the costs of future compliance (EPA, 1997). The following considerations were part of the 1997 analysis:

- Beginning in 2003 (and each year thereafter), the fossil fuel-fired electricity generating units over 25 MW in the SIP call region are assumed to hold NOx allowances during the summer ozone season equal to 489 thousand tons.
- Electricity generating units could trade allowances without restrictions or bank them for later use or sale to another generation unit. Trading could occur within the entire SIP call region.
- Analysis with and without flow controls.

EPA's analysis in 1997 was conducted using the 1996 version of the Integrated Planning Model (IPM). This model is described in EPA, 1996. EPA's analysis shows that on strict economic grounds, (i.e., under minimization of the total direct operating costs over the simulation period) limited banking was forecasted by the IPM based on the scenarios described above. However, EPA believes that some banking, which the IPM could not estimate, should occur when some power plants overcontrol their NOx emissions in order to bank allowances for use in years in which units experience utilization greater than forecasted. More discussion of this issue can be found in Chapter 6 of Volume 1 of this RIA.

2.2 2007 Emissions Estimates for Air Quality Modeling

The initial step in the assessment of changes in air quality attributable to each regulatory alternative is the development of future year 2007 emissions estimates. These estimates generally start off with 1995 emissions data, which are then grown to 2007. Table 2-1 identifies the emissions inputs used for the air quality models. These include nitrogen oxides (NOx), volatile organic compounds (VOC), sulfur dioxide (SO_2), directly emitted particulate matter (primary PM_{10} and $PM_{2.5}$), carbon dioxide (CO), and ammonia (NH_3). RADM and RPM work in tandem and therefore require the same emissions inputs. Emissions are estimated only for the geographic area covered by each air quality modeling domain, which in each case is roughly equivalent to the 37 easternmost states. Air quality estimation is not restricted to the smaller SIP call region because the SIP call regulatory alternatives may result in shifts in power generation, and hence shifts in emissions, among utility sources located inside and outside the SIP call domain. The broad 37 state area modeled for air quality purposes more clearly captures the effects of any modeled shifts in power generation. All emissions estimates were developed using information that was accurate as of March 1998, before final NOx SIP call emissions inventories and control alternatives were established. The emissions inventories and control alternatives proposed in the original November 7, 1997 and supplemental May 11, 1998 Federal Register notices have changed as a result of public comments received on both proposal notices. These changes are not reflected in the air quality modeling results used in the benefits analysis.

The subsections that follow briefly describe emissions development for each emissions sector, including electricity generating utility point sources, other stationary point sources, area and non-road mobile sources, highway mobile sources, and non-anthropogenic sources. A final subsection identifies differences between the air quality modeling emissions inventory and the final emissions inventory, and discusses the implications for interpreting the air quality results used in this analysis.

Table 2-1
Emissions Inputs for Air Quality Models

Air Quality Model	Emissions Inputs
UAM-V	typical summer day hourly VOC and NOx
RADM-RPM	warm season (May - September) and cold season (October - April) NOx, SO_2, SO_4, CO, VOC, and NH_3
S-R Matrix	annual NOx, SO_2, CO, VOC, NOx, primary PM_{10}, primary $PM_{2.5}$, and NH_3

2.2.1 Electricity Generating Unit Point Source Emissions

EPA developed projections of 2007 NOx and SO_2 emissions from electricity generating units (EGUs) using the latest version of the Integrated Planning Model (U.S. EPA, 1998a). The CO and VOC profiles for each EGU are added based on data from EPA's National Emission Trends (NET) inventory projections. Primary PM_{10} and primary $PM_{2.5}$ are derived using IPM-generated ash content data and the latest AP-42 emission factors (U.S. EPA, 1998c). AP-42 emission factors are also used to derive NH_3 emissions. These emissions estimates are made for the 2007 base case and each control alternative.

2.2.2 Non-EGU Point Source Emissions

EPA developed projections of 2007 NOx and VOC emissions using information gathered by the Ozone Transport Assessment Group in 1997. These projections were later revised based on more recent information, including public comments submitted on the proposed NOx SIP call. Emissions of SO_2, primary PM_{10}, primary $PM_{2.5}$, and NH_3 are taken from EPA's NET projections[2]. These emissions estimates are made for the 2007 base case and each control alternative.

2.2.3 Area and Mobile Source Emissions

All area source, non-road mobile source, and highway mobile source emissions are taken directly from EPA's NET projections. Emissions are developed for all counties and then allocated to UAM-V and RADM grid cells. Additional reductions in area and mobile source emissions are not part of the control alternatives, therefore emissions estimates are made for these source categories only for the 2007 base case.

2.2.4 Natural Emissions

Natural emissions come from geogenic, biogenic, and wild fire sources. For some pollutants, natural emissions comprise a significant fraction of total emissions. For example, man-made emissions of ammonia are a small component of total ammonia emissions. The majority of the ammonia that enters the atmosphere is produced by the biological decomposition of organic material in soils, plant residues, and wastes from animals and humans (NAPAP, 1991). Biogenic VOC emissions are developed based on EPA's Biogenic Emissions Inventory System (BEIS) (Pierce et al., 1990). Natural sources of PM emissions (i.e., wind erosion) are taken from the NET. Additional reductions in natural emissions are not part of the control alternatives, therefore emissions estimates for these sources are made only for the 2007 base case.

2.2.5 Summary of 2007 Emissions Projections

Table 3-2 summarizes the major control requirements that are accounted for in the 2007 Base Case emissions projection. These include all federal motor vehicle controls and nonattainment area (NAA)-related controls required by the Clean Air Act, additional reductions from large stationary NOx sources required by the Ozone Transport Commission in the northeast U.S., and a national low emission vehicle (NLEV) standard starting in model year 1999.

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[2] EPA's NET does not currently include estimates of primary $PM_{2.5}$. Primary $PM_{2.5}$ emissions are estimated from primary PM_{10} emissions using regionally derived relationships between PM_{10} and $PM_{2.5}$.

The control requirements included in the alternative policy scenarios modeled for air quality purposes, and hence for the purpose of estimating benefits, are shown in Table 2-3. The tables in Appendix B provide additional information on the emissions associated with the scenarios that are modeled for the benefits analyses. Since the scenarios modeled differ slightly from the regulatory alternatives evaluated in the cost analyses (0.15 trading for EGUs, and 60%/$5,000 for non-EGUs) in Volume 1of this RIA, Table 2-3 also indicates the controls associated with preferred regulatory alternative upon which EPA based the final emissions budgets. The air quality changes associated with the set of control requirements in the actual final emissions budgets have not been estimated in this analysis.

Table 2-4 provides some perspective on the potential differences between the emissions reductions associated with the air quality modeling alternatives and the cost analysis alternatives. The table indicates the percent change in NOx emissions associated with the air quality scenarios that are modeled for the benefits analyses, and the percent changes associated with similar alternatives modeled in the cost analyses. The RADM-RPM reductions for the warm season are generally higher than the annual reductions for the S-R Matrix input. The seasonal RADM-RPM reductions and the annual S-R Matrix reductions can be reconciled by considering the simple linear combination of RADM-RPM warm and cold season emissions. For instance, for the 0.15 trading alternative, the linear combination of the warm and cold season reductions is 24.7% (37.1%*5/12 + 15.8%*7/12), which is very close to the annual S-R Matrix reduction of 24.0%.

Overall, the emission reductions associated with the air quality modeling inputs are larger than the emission reductions associated with the cost analyses. For most of the regulatory alternatives, the difference in modeled point source NOx reductions across the 37 states is about 5%. The difference for EGU sources is small, around 2%, but the difference for non-EGU sources is much larger at about 10%. As indicated in Table 2-3, this is because the air quality modeling inputs for non-EGU sources are based on the proposed emissions budget level; the final emissions budget for non-EGU sources is less stringent than proposed budget. The actual benefits associated with the preferred regulatory alternative and the final emissions budgets will depend exactly on the specific seasonal and geographic distribution of emissions changes.

Table 2-2
2007 Base Case Projection Control Requirements by Major Sector

Major Sector	Major Base Case Requirements
EGU Point Sources	Title IV Phase I and Phase II NOx and SO_2 limits for all boiler types. 250 ton Prevention of Significant Deterioration (PSD) and New Source Performance Standards (NSPS) for NOx, NO_2, VOC, CO, and SO_2. RACT and New Source Review (NSR) NOx limits for all non-waived NAAs. Phase I of the Ozone Transport Commission (OTC) NOx memorandum of understanding (MOU).
Non-EGU Point Sources	VOC and NO_x RACT for all NAAs (except NOx waivers). New control technique guidelines (CTGs) for VOC. OTAG Level 2 NOx controls across OTAG States. MACT standards (primarily affects VOC).
Area Sources	VOC and NOx RACT requirements. New CTGs for VOC. MACT Standards (primarily affects VOC). PM_{10} NAA controls. Onboard vapor recovery (vehicle refueling--VOC). Stage II vapor recovery systems (VOC). Federal rules (consumer/commercial product limits, architectural and industrial maintenance (AIM) coating limits) (VOC).
Nonroad Mobile Sources	Federal Tier 2 and 3 ≥50 hp compression ignition (CI) engine standards (VOC, NOx, PM). Federal Tier 1 and 2 < 50 hp CI engine standards. Federal Phase 1 and 2 small (<1.9 kw) spark ignition (SI) engine standards (CO,VOC, NOx, PM). Federal locomotive standards (VOC, NOx, PM). Federal ≥50 hp CI marine engine standards (VOC, NOx, PM). Federal spark ignition recreational marine engine standards (VOC, NOx, PM).
Highway Mobile Sources	Tier 1 tailpipe standards (CO, VOC, NOx, PM). 49-State (national) LEV program (CO, VOC, NOx, PM). 2004 heavy duty diesel (HDD) engine standards (NOx, VOC) Phase 2 Reid vapor pressure (RVP) limits (CO, NOx, VOC). I/M programs for ozone (VOC, NOx) and carbon monoxide (CO) NAAs. Federal reformulated gasoline for O_3 NAAs (CO, VOC, NOx, SO_2). Diesel fuel sulfur content limits (SO_2). Oxygenated fuel in CO NAAs (CO). Onboard refueling vapor recovery (VOC). Stage 2 refueling vapor recovery (VOC). Enhanced evaporation emission standards (VOC).

Table 2-3
Summary of Regulatory Alternatives for the 2007 Air Quality Modeling: NOx Control Requirements by Major Sector

	Control Requirements by Alternative					
Major Sector	**0.25 Trading**	**0.20 Trading**	**Regionality 1**	**0.15 Trading**	**0.12 Trading**	**Preferred Alternative**
EGU Point Sources[a]	Emissions budget based on 0.25 lb/mmBTU limit	Emissions budget based on 0.20 lb/mmBTU limit	Emissions budget based on 0.15 lb/mmBTU limit in NE and 0.20 lb/mmBTU in MW/SE [b]	Emissions budget based on 0.15 lb/mmBTU limit	Emissions budget based on 0.12 lb/mmBTU limit	Emissions budget based on 0.15 lb/mmBTU limit
Non-EGU Point Sources	60% (UAM-V) or 70% (RPM/S-R) reduction for >250 mmBtu/hour input capacity; RACT for all other sources >1 tpd [c]	70% reduction for >250 mmBtu/hour input capacity; RACT for all other sources >1 tpd	70% reduction for >250 mmBtu/hour input capacity; RACT for all other sources >1 tpd	70% reduction for >250 mmBtu/hour input capacity; RACT for all other sources >1 tpd	70% reduction for >250 mmBtu/hour input capacity; RACT for all other sources >1 tpd	60% reduction for boilers and turbines, 90% reduction for reciprocating IC engines, 30% reduction for cement kilns[d]
Area	No additional control requirements.					
Nonroad Mobile Sources	No additional control requirements.					
Highway Mobile Sources	No additional control requirements.					

[a] All EGU control requirements apply to fossil-fuel fired units greater than 25 MW.

[b] NE states include Connecticut, Delaware, District of Columbia, Massachusetts, Maryland, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Virginia, and West Virginia. MW/SE states include Alabama, Georgia, Illinois, Indiana, Kentucky, Michigan, Missouri, North Carolina, South Carolina, Tennessee, and Wisconsin. Emissions trading is allowed within each region but not across regions.

[c] A 60% reduction strategy was used in the UAM-V and RADM modeling. To save additional time for the S-R Matrix modeling, a 70% reduction strategy was used to be consistent with the remaining regulatory alternatives.

[d] All non-EGU point source requirements for the preferred alternative apply to sources > 250 mmBtu/hour input capacity, or where such data does not apply, > 1 ton per day NOx emissions. For IC engines and cement manufacturing, the emission reduction requirements correspond to the highest reduction achievable for the source category at less than $5,000 per ozone season ton.

Table 2-4
Percent Change from 2007 Base Case in 37-State NOx Emissions

Major Sector	0.25 Trading	0.20 Trading	Regionality 1	0.15 Trading	0.12 Trading
Ozone Season NOx Corresponding to UAM-V Inputs					
EGU Sources	-26.1	-35.3	-39.0	-44.5	-49.2
Non-EGU Sources	-21.9	-27.7	-27.7	-27.7	-27.7
Total Point Sources	-24.7	-32.7	-35.2	-38.8	-41.8
Warm Season Annualized NOx Corresponding to RADM-RPM Inputs [a]					
EGU Sources	-25.7	-34.7	-38.4	-43.7	-48.5
Non-EGU Sources	-15.8	-26.0	-25.9	-25.9	-25.8
Total Point Sources	-22.0	-31.5	-33.8	-37.1	-40.1
Cold Season Annualized NOx Corresponding to RADM-RPM Inputs [a]					
EGU Sources	-9.1	-9.1	-9.1	-9.2	-9.4
Non-EGU Sources	-16.0	-26.3	-26.3	-26.3	-26.3
Total Point Sources	-11.8	-15.8	-15.8	-15.8	-15.9
Annual NOx Corresponding to S-R Matrix Inputs					
EGU Sources	-15.9	-19.8	-21.3	-23.6	-25.8
Non-EGU Sources	-24.5	-24.5	-24.5	-24.5	-24.5
Total Point Sources	-19.3	-21.6	-22.6	-24.0	-25.3
Ozone Season NOx Corresponding to Cost Analyses					
EGU Sources	-24.9	-33.7	-37.2	-42.3	-47.0
Non-EGU Sources [b]	-17.1	-17.1	-17.1	-17.1	-17.1
Total Point Sources	-22.1	-27.7	-30.0	-33.3	-36.2

[a] The RADM-RPM uses seasonal emissions inputs. The warm season is defined as the 5 months May - September, and the cold season is defined as the 7 months October - April. A simple linear combination of the 5-month and 7-month NOx reductions will yield an approximation of the annual NOx reductions.

[b] The NOx reduction estimates for the non-EGU sources is based on the 60%/$5,000 per ton alternative, which is described as the "preferred alternative" in Table 2-3.

2.3 References

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Chapter 3. AIR QUALITY IMPACTS

This chapter describes the methods for estimating air quality for the 2007 base case and several alternative policy scenarios. EPA has estimated the air quality changes that have been linked to health, welfare, and ecological benefits, including changes in ambient particulate matter (PM_{10} and $PM_{2.5}$), ambient ozone, nitrogen deposition, and visibility degradation. First, emission levels corresponding to the base case and alternative policy scenarios are estimated, and this data is used to run air quality models. Using the methods identified and described in Chapter 4, air quality changes are then associated with human populations and ecosystems to estimate changes in health and welfare effects.

EPA has used a regional-scale version of the Urban Airshed Model (UAM-V) to estimate ozone air quality. The Regional Acid Deposition Model (RADM) is used to estimate nitrogen deposition. To estimate PM air quality and visibility degradation, EPA has used both the Regional Particulate Model (RPM) and a Source-Receptor Matrix (S-R Matrix) based on the Climatological Regional Dispersion Model (CRDM). Two different PM models are used because the results of each model can be interpreted to represent the range of atmospheric chemistry that may exist in the year 2007. The results of RPM are used to represent a future eastern U.S. atmosphere where acid sulfate levels are still high enough to control atmospheric chemistry, and more specifically ammonium nitrate particle formation. In this circumstance, reductions in NOx emissions may result in non-linear responses in total fine particle levels, involving both decreases and increases[1]. The results of the S-R Matrix are used to represent a future eastern U.S. atmosphere where acid sulfate levels do not dominate particle formation chemistry. In this case, reductions in NOx emissions would be expected to result more directly in reductions in PM.

Section 3.1 covers the estimation of ozone air quality using UAM-V. Section 3.2 covers the estimation of particulate matter air quality using RPM, and section 3.3 discusses the S-R Matrix. Section 3.4 discusses the estimation of nitrogen deposition using RADM. Finally, section 3.5 covers the estimation of visibility degradation using both RPM and the S-R Matrix.

3.1 Ozone Air Quality Estimates

The EPA has used the emissions inputs discussed in Chapter 2 with a regional-scale version of the Urban Airshed Model (UAM-V) to estimate ozone air quality. UAM-V was the primary modeling tool relied on by the OTAG process that provided the foundation for the NOx SIP call. Because it accounts for spatial and temporal variations as well as differences in the reactivity of emissions, the UAM-V is ideal for evaluating the air-quality effects of emission control scenarios.

Model inputs are prepared from observed meteorological, emissions, and air quality data for the episode days using prognostic meteorological modeling and/or diagnostic and interpolative modeling techniques. The model is then applied with these inputs, and the results are evaluated to determine model performance. Once the model results have been evaluated and determined to perform within prescribed

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[1] See Appendix D for a more thorough discussion of non-linear chemistry and fine particle formation.

levels, the same base-case meteorological inputs are combined with *modified* or *projected* emission inventories to simulate possible alternative future emission scenarios.

For this study, EPA uses the UAM-V modeling system for the eastern U.S. The modeling system is applied for a base-year of 1995 and for several future-year scenarios, including a 2007 baseline and several control strategy options. The UAM-V modeling system requires a variety of input files that contain information pertaining to the modeling domain and simulation period. These include gridded, day-specific emissions estimates and meteorological fields; initial and boundary conditions; and land-use information.

3.1.1 Modeling Domain

The modeling domain for this application is identical to that used by OTAG in their modeling analyses. The domain encompasses most of the eastern U.S. and consists of two grids, as illustrated in Figure 3-1. The horizontal resolution for the inner grid, or fine grid, which is the shaded area of Figure 3-1, is approximately 12 km; this grid consists of seven vertical layers. The horizontal resolution for the outer grid, which is the unshaded area of Figure 3-1, is approximately 36 km; this grid consists of five vertical layers.The top of the modeling domain is 4000 meters above ground level.

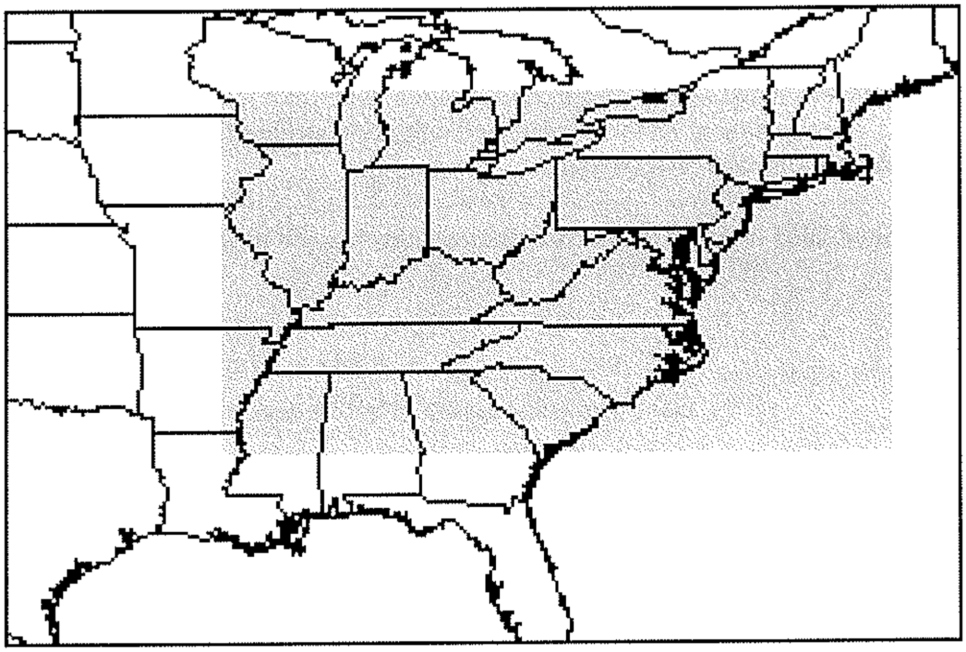
3.1.2 Simulation Periods

The four OTAG multi-day simulation periods are used in this study to prepare the future-year ozone profiles. These include the following 31 days: 4-11 July 1988, 16-21 July 1991, 22-29 July 1993, and 4-18 July 1995 (the start-up days for each simulation period are not listed here). All four simulation periods are characterized by high ozone concentrations in one or more portions of the eastern U.S.; numerous exceedances of the 1-hour National Ambient Air Quality Standard for ozone were recorded during each of the periods.

3.1.3 UAM-V Model Output

Standard output from the UAM-V modeling system includes: (1) hourly, gridded surface-layer ozone concentrations (provided as hourly averages); (2) instantaneous ozone values for all grid cells and layers for each hour of the simulation; and (3) detailed information on the sub-grid-scale plume-in-grid treatment. For this study, hourly, gridded, surface-layer ozone concentrations were extracted from the file containing hourly average ozone values. This information was used in the calculation of adjustment factors as described in the following section.

Figure 3-1
UAM-V Modeling Domain



3.1.4 Converting Episode Estimates to Full-Season Profiles

The UAM-V runs generate surface layer hourly average ozone values for each of the 31 episode days for a total of 744 hourly predictions for each model grid cell. These predictions are used in conjunction with actual 1995 observations to generate ozone values for the entire ozone season.[2]

This procedure uses observed hourly ozone data obtained from EPA's AIRS monitor database for 1995. Individual monitors are mapped onto the gridded UAM-V output, and the concentrations of the corresponding grid cells are used to calculate an adjustment factor for each monitor-year-scenario. The adjustment factor at monitor *j* is calculated as:

$$Adjustment\ factor_j = \frac{Mean(Conc_{j,\ 2007\ policy\ option} - 0.04)}{Mean(Conc_{j,\ Base\ year} - 0.04)}$$

where $Conc_{j,\,year}$ is the estimated hourly ozone concentration at monitor j, in ppm, for the indicated year and policy option. The adjustment factor is calculated only for concentrations above continental background, which is assumed to be 0.04 ppm.

The estimated 2007 hourly ozone concentrations are obtained as follows:

$$Conc_{j,\ hour\ i,\ 2007\ policy\ option} = (Conc_{j,\ hour\ i,\ 1995} - 0.04)\ x\ (Adjustment\ Factor) + 0.04$$

$$Conc_{j,\ hour\ i,\ 2007\ policy\ option} = Conc_{j,\ hour\ i,\ 1995}$$

$$for\ Conc_{j,\ hour\ i,\ 1995} \geq 0.04$$

$$for\ Conc_{j,\ hour\ i,\ 1995} < 0.04$$

Therefore, values less than 0.04 ppm are assumed insensitive to control strategies and are not adjusted.

These air quality modeling procedures result in a set of estimated hourly ozone levels for each existing monitor for every hour in 2007 for the baseline and for each policy option. Certain hourly observations are identical in all scenarios (specifically hours outside the ozone season and 1995 observations below 0.04 ppm). Hours with ozone levels above 0.04 in the base year have new predicted values based on the average change in the UAM-V modeling results for the four modeled July periods.

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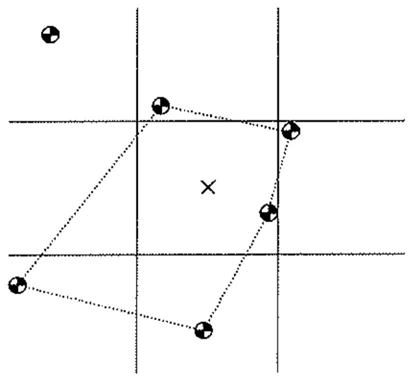
[2] The 5-month ozone season for this analysis is defined as May to September for health benefits. For agricultural benefits for some crops, the relevant growing season extends into April and into October and November. In this analysis, no changes in ozone concentrations are assumed to occur outside the 5-month ozone season. However, the ozone metric (SUM06) used to estimate certain crop yield benefits requires that the baseline level of ozone concentrations be estimated for months outside the 5-month ozone season.

3.1.5 Extrapolating from Monitored to Unmonitored Grid Cells

Given monitor-specific hourly ozone data, ozone measures (e.g., daily average) for each grid-cell are obtained in two steps: (1) hourly data are converted to an ozone measure of interest, such as the daily average, and (2) monitor-specific ozone measures are used to estimate ozone measures at each grid cell. The conversion from hourly data to ozone measures of interest is straightforward. The estimation of ozone measures at each grid cell uses a convex polygon interpolation procedure method.

Diagram 1: Convex Polygon



The convex polygon method interpolates air quality estimates from the monitors to the center of each population grid cell. The convex polygon is a generalization of the planar interpolation method. Rather than limit the selection of monitors to, say, three, the convex polygon method identifies the set of monitors that best "surrounds" the center of each grid cell. The result of the convex polygon method is illustrated in Diagram 1. The set of monitors that best surround the grid cell are determined by identifying which monitor is closest (considering both angular direction and horizontal distance) in each direction from the grid cell center. The set of monitors found using this approach will form a convex polygon around the grid cell center. The agricultural and forest effects analysis also uses air quality interpolated using the convex polygon method. However, calculating the benefits for these welfare categories is best accomplished by using air quality data at the county level, rather than the grid cell level. Therefore, the convex polygon approach is used to estimate the ozone levels at the county centroid locations for these analyses.

In an effort to avoid extrapolating from monitored grid cells that are too far removed from the unmonitored cell to be representative, yet still maintain relatively complete geographic coverage of the UAM-V modeling domain, monitors are dropped from the set of defining monitors for a population grid cell if the monitor is greater than a 200 km. Grid-cells that have no monitors within 200 km are *dropped* from the health effects analysis. An exception to this rule is made for the analysis of agricultural and forest effects which uses the SUM06 index at the county level.[3] Since ozone monitors are generally located in areas of greatest population density, rather than in rural areas where crop and forest land are more dense, the 200 km rule does not provide sufficient coverage in many rural counties in the OTAG region. Therefore, for the SUM06 data set a 1,000 km range is used for any county that is not within 200 km of a monitor. This affects 214 counties, primarily those on the western edge of the region, including all of South Dakota. After determining the final set of surrounding monitors, the location's air quality level is calculated as an inverse-distance weighted average of the selected monitors.

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[3] The SUM06 is a crop exposure index which sums the ozone concentration for every hour that exceeds 0.06 ppm, within a 12-hour period from 8:00 A.M. to 8:00 P.M.

3.1.6 Ozone Air Quality Results

A summary of the ozone air quality profiles used to assess the benefits of alternative policy scenarios is presented in Table 3-1. The average change in daytime hourly ozone values across the entire UAM-V model domain ranges from -0.0005 ppm to -0.0008 ppm across alternatives. The population-weighted average change across the same model domain ranges from -0.0004 person-ppm to -0.0007 person-ppm. The SUM06 index used in the agriculture and forest benefits analysis indicates a range of changes from -9 to -16 percent.

Population-weighted changes in predicted 1-hour average and 8-hour average concentrations above the level of each ambient air quality standard are presented in Appendix B. These changes are estimated for the total exposed population and for various subpopulations, including minority groups, children, the elderly, and the impoverished. In the SIP call states, the predicted decline in total population exposure above the 1-hour ozone standard level ranges from 51% to 74%. The predicted decline in total population exposure above the 8-hour ozone standard level ranges from 31% to 51%.

Table 3-1
Summary of UAM-V Derived Hourly Ozone Air Quality for Daylight Hours (7am to 7pm)
During the Ozone Season

		Change Relative To 2007 Base Case[a]				
Statistic	**2007 Base Case**	**0.25 Trading**	**0.20 Trading**	**Reg. 1**	**0.15 Trading**	**0.12 Trading**
Minimum (ppm) [b]	0.0230	-0.0020	-0.0027	-0.0029	-0.0029	-0.0036
Maximum (ppm) [b]	0.0532	0.0003	0.0008	0.0004	0.0004	0.0004
Spatial Average (ppm)	0.0426	-0.0005	-0.0006	-0.0007	-0.0007	-0.0008
Population-Weighted Average (person-ppm) [c]	0.0411	-0.0004	-0.0005	-0.0006	-0.0006	-0.0007
SUM06 [d]	25.35	-2.37	-3.12	-3.28	-3.67	-4.14

[a] The change is defined as the control case value minus the base case value.

[b] The base case minimum (maximum) is the value for the county with the lowest (highest) seasonal 7am to 7 pm average, where the season is defined as May through September. The change relative to the base case picks the minimum (maximum) from the set of changes in all counties.

[c] Calculated by summing the product of the projected 2007 county population and the estimated 2007 county seasonal ozone concentration, and then dividing by the total population.

[d] SUM06 is defined as the cumulative sum of hourly ozone concentrations over 0.06 ppm that occur from 8am to 8pm in the months of May through September. (As noted, the other statistics in this Table are for the hours of 7am to 7pm.)

Note that only ozone concentrations during daylight hours are assumed to be affected by the control strategies.[4] UAM-V predictions of changes in nighttime values have not been validated in this analysis, and therefore EPA has assumed no changes in nighttime values. Benefit values are therefore potentially understated to the extent that the policy alternatives evaluated in this analysis result in improvements in nighttime values, and to the extent that nighttime values are associated with health and welfare effects.

The air quality technical support document for this RIA (Abt Associates, 1998) contains maps showing the base case ozone concentrations and ozone concentration changes for each of five regulatory alternatives (0.25 Trading, 0.20 Trading, Regionality 1, 0.15 Trading, and 0.12 Trading). These maps only convey information about the 5-month ozone season used for the health benefits analysis.

3.2 PM Air Quality Estimates Using RPM

Ambient concentrations of PM are composed of directly emitted particles and of secondary aerosols of sulfate, nitrate, ammonium, and organics. The EPA has used the emissions inputs discussed in section 3.1 with both the Regional Particulate Model (RPM) and the Source-Receptor Matrix (S-R Matrix) to estimate PM air quality. Relative to the S-R Matrix, RPM is designed to more realistically account for the complex chemical interactions that take place in the atmosphere in the secondary formation of PM. This section discusses the use of RPM and section 3.4 discusses the S-R Matrix.

RPM is an "Eulerian" model that functions in tandem with the Regional Acid Deposition Model (RADM). RPM predicts the chemistry, transport, and dynamics of the secondary aerosols of sulfate, nitrate, ammonium, and organics. An evaluation of RPM predictions of sulfate, nitrate, and ammonium against the Clean Air Status and Trends Network (CASTNet) was performed and RPM's predictions were deemed reasonable for policy assessment purposes. RPM predictions of organic aerosol were not used because RPM has a large under prediction for organics, the sources of which have not yet been thoroughly characterized. Inputs to RPM include RADM-processed fields of water and RADM-predicted fields of oxidants, nitric acid (for total nitrate), and ammonia (for total ammonia). The field of total nitrate is partitioned between particulate nitrate and nitric acid, depending on numerous factors, including the availability of ammonia, relative acid sulfate levels, and ambient temperature. RPM also uses a subset of the RADM emissions inputs and the RADM meteorological fields as inputs.

3.2.1 Modeling Domain

The RPM domain is also the same as RADM, covering the eastern U.S. and southern Canada from James Bay to the Florida Keys (see Figure 3-2). The RPM grid size and vertical resolution is the same as RADM's, 80-km and 15 layers up to the top of the free troposphere, respectively, with the lowest layer having a nominal height of 40 meters. This relatively large grid areas (e.g., compared to UAM-V) is though reasonable for estimating large scale deposition, but introduces uncertainty in estimating the location of PM changes that are related to estimating health effects in the benefits analysis.

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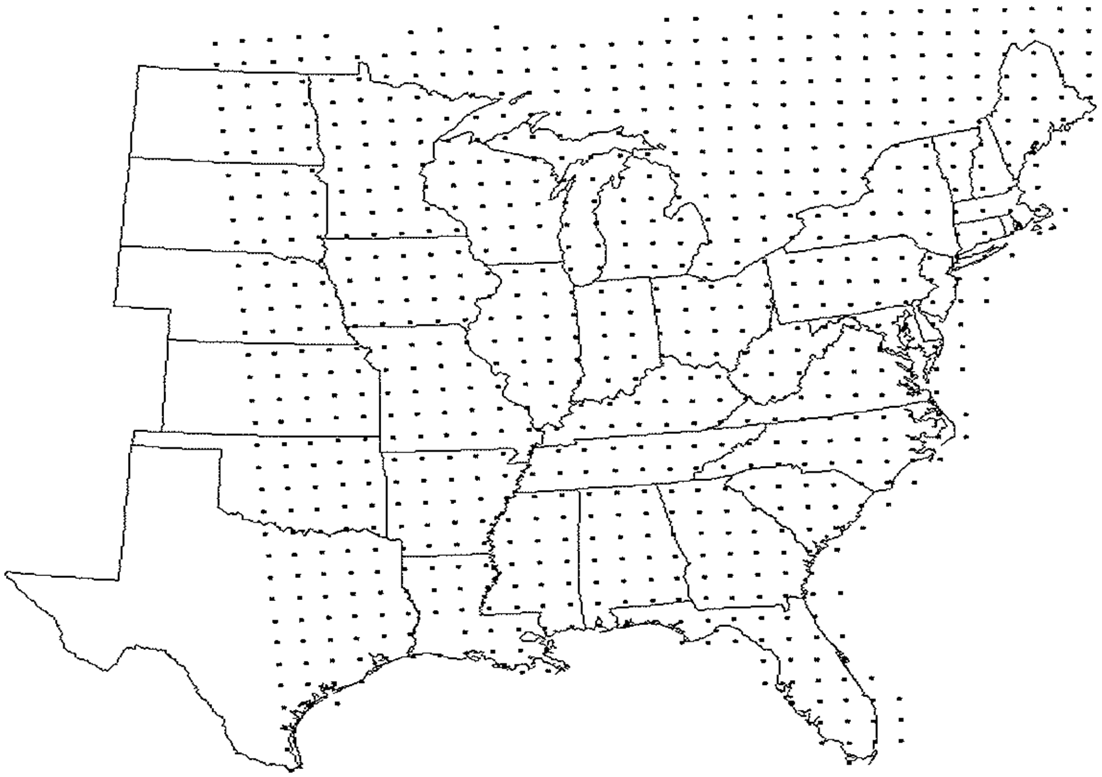
[4] In the UAM-V analysis, daytime hours are 7:00 A.M. to 7:00 P.M.

Figure 3-2
RADM-RPM Modeling Domain*



*Note: The dots are located at the center of the 80km grid squares that cover the eastern U.S. and southern Canada.

3.2.2 Simulation Periods

To develop annual estimates with seasonal controls, an aggregation set of 30 meteorological cases is separated into a warm season set and a cold season set. Because RADM predicts chemistry on a synoptic, or daily, time scale (chemical meteorology) an aggregation technique developed during NAPAP is used to calculate annual estimates of acidic deposition. The development and evaluation of the aggregation simulation set is described by Brooks et al., 1995. Meteorological cases with similar 850-mb wind flow patterns were grouped by applying cluster analysis to classify the wind flow patterns from 1982 to 1985, resulting in 19 sampling groups, or strata. Meteorological cases were randomly selected from each stratum; the number selected was based on the number of wind flow patterns in that stratum relative to the number of patterns in each of the other strata, to approximate proportionate sampling. A total of thirty cases are used in the current aggregation approach. Each case is run for 5 days, using a separate initial condition for each season specific to the scenario being run. Outputs from only the last 3 days are used to avoid the influence of initial conditions. For each emissions scenario modeled, seasonal initial conditions are developed by running for 10 days with those emissions after starting with ambient concentrations representative of clean continental conditions. Results for the 30 selected 3-day cases are weighted according to the strata sampling frequencies to form annual averages. Application of the aggregation technique is described in Dennis et al, 1990. Note, the aggregation method results in an annual average produced by meteorology that is representative of many years of meteorology, a decade or more, rather than for a single, given year.

While the aggregation method was developed for acidic deposition, it has been extended to daily average particulate concentrations to calculate the annual mean, median and 90th percentile of the distribution. The applicability of the aggregation method to particulate matter was studied by Eder, et al., 1996 using an extinction coefficient (b_{ext}) for mid-day estimate from human observations of visible range at airports (Husar and Wilson, 1993). The thirty RADM aggregation cases were found to be very representative from an extinction coefficient (inferred fine particulate matter) perspective and sufficient to derive annual estimates of fine particulate matter.

3.2.3 RPM Model Outputs

RPM outputs used in this analysis include ambient concentrations (measured in units of micrograms per cubic meter, μg/m^3) of particulate SO_4^-, NO_3^-, and NH_4^{+-}. The outputs produced by the simulation period aggregation method described in section 3.3.2 include the annual mean of daily average ambient concentrations, and each decile of the distribution of daily average ambient concentrations. However, the health effect concentration-response functions that are used to estimate changes in health effects for each policy scenario require estimates of total PM. Section 3.3.4 discusses the procedures used to estimate the remaining fraction of total PM at each location.

3.2.4 Development of Total PM Estimates

RPM provides the mean, the median, and the peak (90th percentile value) of daily concentrations, but only for the major *portion* of PM that will change as a result of the NOx SIP call -- i.e., the nitrate, sulfate, and ammonium components (NSA). According to the latest assessment of PM data for the

NAAQS review, NSA comprise 48.2% of total fine particulate in the eastern U.S. (U.S. EPA, 1996a). To proceed with the RPM results, it is necessary to first use the NSA concentrations to estimate total PM concentrations at each location under the baseline and each control scenario for the NOx SIP call[5].

A first step in using information supplied by RPM is to estimate distributional statistics for total PM, using ambient air quality data currently being developed for the CAAA §812 analysis. The location-specific inputs available from RPM and the upcoming §812 analysis are as follows:

- mean and peak PM in the §812 data ($PM_{mean,\ 812}$, $PM_{0.90,\ 812}$);
- mean and peak NSA in the §812 data ($NSA_{mean,\ 812}$, $NSA_{0.90,\ 812}$);
- mean, median, and peak NSA in the NOx SIP call baseline ($NSA_{mean,\ baseline}$, $NSA_{median,\ baseline}$, $NSA_{0.90,\ baseline}$);
- mean, median, and peak NSA in each control scenario of the NOx SIP call ($NSA_{mean,\ control}$, $NSA_{median,\ control}$, $NSA_{0.90,\ control}$).

Subtracting the mean NSA from mean total PM, one obtains the "other" component of PM (which includes such components as soil and elemental carbon):

$$\mathrm{Other}_{mean,\ 812} = \mathrm{PM}_{mean,\ 812} - \mathrm{NSA}_{mean,\ 812}$$

It is assumed that the mean of this (location-specific) "other" component is the same in the NOx SIP call baseline as it is in the §812 data:

$$\mathrm{Other}_{mean,\ baseline} = \mathrm{Other}_{mean,\ 812} .$$

Total PM is estimated in the baseline as:

$$\mathrm{PM}_{mean,\ baseline} = \mathrm{Other}_{mean,\ baseline} + \mathrm{NSA}_{mean,\ baseline} .$$

To obtain an estimate of the 90th percentile level of PM in the baseline, it is assumed that the proportion (p) of $NSA_{mean,\ baseline}$ to $PM_{mean,\ baseline}$ is constant across days at the same location:

$$p = \mathrm{NSA}_{mean,\ baseline} / \mathrm{PM}_{mean,\ baseline} = \mathrm{NSA}_{i,\ baseline} / \mathrm{PM}_{i,\ baseline} ,$$

where i denotes the ith day. Given a constant ratio, p, the peak (90th percentile) day for baseline PM is the same day as the peak day for baseline NSA. This implies:

$$\mathrm{PM}_{0.90,\ baseline} = (1/p) * \mathrm{NSA}_{0.90,\ baseline}$$

In the last step, given the mean and 90th percentile point of the distribution of daily PM concentrations ($PM_{mean,\ baseline}$ and $PM_{0.90,\ baseline}$), and assuming that the distribution can be fit well by a

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[5] The RPM estimates of NSA are anhydrous estimates. However, ambient measurements of NSA do contain water, which can increase the total NSA mass by as much as 10% to 50%. Therefore, the estimates of total NSA mass changes derived from RPM understate total NSA mass changes.

Gamma distribution, the analysis uses a maximum likelihood estimation to estimate the parameters of the Gamma distribution that are most consistent with the estimated mean and peak values. A distribution of daily PM values based on NSA components predicted by RPM may then be generated for the baseline scenario. A similar procedure is used to estimate PM values in the control scenarios. Additional detail on these procedures can be found in Abt, 1998.

3.2.5 RPM PM Air Quality Results

Table 3-2 provides a summary of the predicted ambient PM_{10} and $PM_{2.5}$ concentrations used in this study. Since only the NSA fraction of total PM changes, the estimates of changes for PM_{10} and $PM_{2.5}$ are identical. The concentration changes are generally very small. For the 0.15 option, annual mean PM changes range from an increase of 0.29 $\mu g/m^3$ to a decrease of -0.49 $\mu g/m^3$, with an average annual mean change across the RPM domain of -0.06 $\mu g/m^3$.

Population-weighted changes in RPM predicted annual mean $PM_{2.5}$ and PM_{10} concentrations above the level of each ambient air quality standard are presented in Appendix B. These changes are estimated for the total exposed population and for various subpopulations, including minority groups, children, the elderly, and the impoverished. In the SIP call states, the predicted decline in total population exposure above the $PM_{2.5}$ annual standard level ranges from 5% to 15%. There is no predicted change in total population exposure above the PM_{10} annual standard level because there is no predicted baseline exposure above the standard.

The air quality technical support document for this RIA (Abt Associates, 1998) contains maps showing the base case PM concentrations and PM concentration changes generated using RPM for each of five regulatory alternatives (0.25 Trading, 0.20 Trading, Regionality 1, 0.15 Trading, and 0.12 Trading).

3.3 PM Air Quality Estimates Using the S-R Matrix

The Source-Receptor Matrix (S-R Matrix) reflects the relationship between annual average PM concentration values at a single receptor in each county (a hypothetical design value monitor sited at the county population centroid) and the contribution by PM species to this concentration from each emission source (E.H. Pechan, 1996). The receptors that are modeled include all U.S. county centroids plus receptors in 10 Canadian provinces and 29 Mexican cities/states. The methodology used in this RIA for estimating PM air quality concentrations using the S-R Matrix is similar to the method used in the July 1997 PM and Ozone NAAQS RIA (U.S. EPA, 1997a). The S-R Matrix was developed using the Climatalogical Regional Dispersion Model (CRDM), and has been calibrated using 1993 - 1995 PM_{10} and $PM_{2.5}$ monitoring data. These calibration factors, referred to as "normalization factors," are applied to all S-R Matrix predictions.

Table 3-2
Summary of RPM Derived PM Air Quality

		Change Relative to 2007 Base Case[a]				
Statistic	**2007 Base Case**	**0.25 Trading**	**0.20 Trading**	**Reg. 1**	**0.15 Trading**	**0.12 Trading**
Minimum Annual Mean PM_{10} ($\mu g/m^3$) [b]	15.45	-0.49	-0.46	-0.45	-0.49	-0.52
Maximum Annual Mean PM_{10} ($\mu g/m^3$) [b]	35.91	0.24	0.24	0.26	0.29	0.18
Average Annual Mean PM_{10} ($\mu g/m^3$)	26.76	-0.04	-0.05	-0.05	-0.06	-0.12
Population-Weighted Average Annual Mean PM_{10} (person-$\mu g/m^3$) [c]	26.46	-0.03	-0.05	-0.05	-0.05	-0.13
Minimum Annual Mean $PM_{2.5}$ ($\mu g/m^3$) [b]	6.65	-0.49	-0.46	-0.45	-0.49	-0.52
Maximum Annual Mean $PM_{2.5}$ ($\mu g/m^3$) [b]	22.63	0.24	0.24	0.26	0.29	0.18
Average Annual Mean $PM_{2.5}$ ($\mu g/m^3$)	14.96	-0.04	-0.05	-0.05	-0.06	-0.12
Population-Weighted Average Annual Mean $PM_{2.5}$ (person-$\mu g/m^3$) [c]	14.53	-0.03	-0.05	-0.05	-0.05	-0.13

[a] The change is defined as the control case value minus the base case value. Note that there is no difference between the changes in $PM_{2.5}$ and PM_{10} because RADM/RPM only estimates the change in nitrates and sulfates which are both in the $PM_{2.5}$ fraction.

[b] The base case minimum (maximum) is the value for the county with the lowest (highest) annual average. The change relative to the base case picks the minimum (maximum) from the set of changes in all counties.

[c] Calculated by summing the product of the projected 2007 county population and the estimated 2007 county PM concentration, and then dividing by the total population.

3.3.1 Climatological Regional Dispersion Model

The CRDM uses assumptions similar to the Industrial Source Complex Short Term (ISCST3), an EPA-recommended short range Gaussian dispersion model. CRDM incorporates terms for wet and dry deposition and chemical conversion of SO_2 and NOx, and uses climatological summaries (annual average mixing heights and joint frequency distributions of wind speed and direction) from 100 upper air meteorological sites throughout North America. Meterological data for 1990 coupled with emissions data from version 2.0 of the 1990 National Particulate Inventory were used to develop the S-R Matrix.

In order to evaluate the performance of the Phase II CRDM, model-predicted PM concentrations and measured ambient PM concentrations were compared. Measured annual average PM concentrations by chemical species from the Interagency Monitoring for Protection of Visual Environments (IMPROVE) network were examined for the three-year period March 1988 - February 1991. This period was chosen because it relates closely to 1990 emissions and meteorological data used in the CRDM. Since the IMPROVE network monitors are primarily concerned with evaluating visibility impairment in predominantly rural Class I areas, these comparisons are incomplete due to the lack of coverage in urban areas. With the exception of the fugitive dust component of $PM_{2.5}$ and PM_{10}, modeled and measured concentrations of sulfate, nitrate and organics are comparable (Latimer, 1996).

The CRDM has also been benchmarked against the RADM-RPM for the Eastern U.S. using 1990 emissions and meteorology (U.S. EPA, 1997b). RADM-RPM incorporates more comprehensive physics and chemistry to enable better characterization of secondarily-formed pollutants than Lagrangian-based methods. In general, the CRDM results show a similar trend in sulfate and nitrate concentrations within the same modeling region. Also, the CRDM-predicted annual average concentrations of sulfate are within the range of RADM-RPM base-case predictions. Relative to RADM-RPM base case results, CRDM appears to overpredict nitrate concentrations in the Midwest and underpredict nitrate concentrations in the Mid-Atlantic states.

3.3.2 Development of the S-R Matrix

To develop the S-R Matrix, a nationwide total of 5,944 sources (i.e., industrial point, utility, area, nonroad, and motor vehicle) of primary and precursor emissions were modeled with CRDM. In addition, secondary organic aerosols formed from anthropogenic and biogenic VOC emissions were modeled. Natural sources of PM_{10} and $PM_{2.5}$ (i.e., wind erosion and wild fires) were also included. Emissions of SO_2, NOx, and ammonia were modeled in order to calculate ammonium sulfate and ammonium nitrate concentrations, the primary particulate forms of sulfate and nitrate. The CRDM produced a matrix of transfer coefficients for each of these primary and particulate precursor pollutants. These coefficients can be applied to the emissions of any unit (area source or individual point source) to calculate a particular source's contribution to a county receptor's total annual average PM_{10} or $PM_{2.5}$ concentration. Each individual unit in the inventory is associated with one of the modeled source types (i.e., area, point sources with effective stack height of 0 to 250 m, 250 m to 500 m, and individual point sources with effective stack height above 500 m) for each county.

The S-R Matrix transfer coefficients were adjusted to reflect concentrations of secondarily-formed particulates (Latimer, 1996). First, the transfer coefficients for SO_2, NOx, and ammonia were multiplied by the ratios of the molecular weights of sulfate/SO_2, nitrate/nitrogen dioxide and ammonium/ammonia to obtain concentrations of sulfate, nitrate and ammonium.[6] The relative concentrations in the atmosphere of ammonium sulfate and ammonium nitrate depend on complex chemical reactions. In the presence of sulfate and nitric acid (the gas phase oxidation product of NOx), ammonia reacts preferentially with sulfate to form particulate ammonium sulfate rather than react with nitric acid to form particulate ammonium nitrate. Under conditions of excess ammonium and low temperatures, ammonium nitrate forms. For each county receptor, the sulfate-nitrate-ammonium equilibrium is estimated based on the following simplifing assumptions:

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[6] Ratio of molecular weights: Sulfate/SO_2= 1.50; nitrate/nitrogen dioxide = 1.35; ammonium/ammonia = 1.06.

- All sulfate is neutralized by ammonium;
- Ammonium nitrate forms only when there is excess ammonium;
- Because ammonium nitrate forms only under relatively low temperatures, annual average particle nitrate concentrations are divided by four assuming that sufficiently low temperatures are present only one-quarter of the year.

Finally, the total particle mass of ammonium sulfate and ammonium nitrate is calculated.[7]

For application to the NOx SIP call, emissions data for only those counties located in the 37 OTAG states plus the District of Columbia are used. Because nationwide emissions are not used, the S-R Matrix results are incomplete for air quality predictions in the counties located in states along the western border of the OTAG domain. For example, emissions from New Mexico are expected to have a significant downwind impact on ambient PM concentrations in neighboring counties in Texas. However, New Mexico emissions are not estimated in this analysis. Incomplete air quality predictions for the six western border states make unreliable any analysis that imposes a threshold for health effects (see Chapter 11). As shown in Figure 3-3, EPA has chosen not to include the air quality results from the six "buffer" states in the benefits analyses that are performed using the S-R Matrix results. Since the 31 remaining states are generally located more than 525 km (approximately 330 miles) from the states for which emissions information is not available, the air quality results for the 31 states is believed to be more reliable.

3.3.3 Fugitive Dust Adjustment Factor

As indicated in subsection 3.4.1, the 1990 CRDM predictions for fugitive dust are not consistent with measured ambient data. The CRDM-predicted average fugitive dust contribution to total $PM_{2.5}$ mass is 31% in the East and 32% in the West (E.H. Pechan, 1997b). Speciated monitoring data from the IMPROVE network show that minerals (i.e., crustal material) comprise approximately 5% of $PM_{2.5}$ mass in the East and approximately 15% of $PM_{2.5}$ mass in the West (U.S. EPA, 1996a). These disparate results suggest a systematic overbias in the fugitive dust contribution to total PM. This overestimate is further complicated by the recognition that the 1990 NPI significantly overestimates fugitive dust emissions. The most recent National Emissions Trends inventory indicates that the NPI overestimates fugitive dust PM_{10} and $PM_{2.5}$ emissions by 40% and 73% respectively[8] (U.S. EPA, 1997c).

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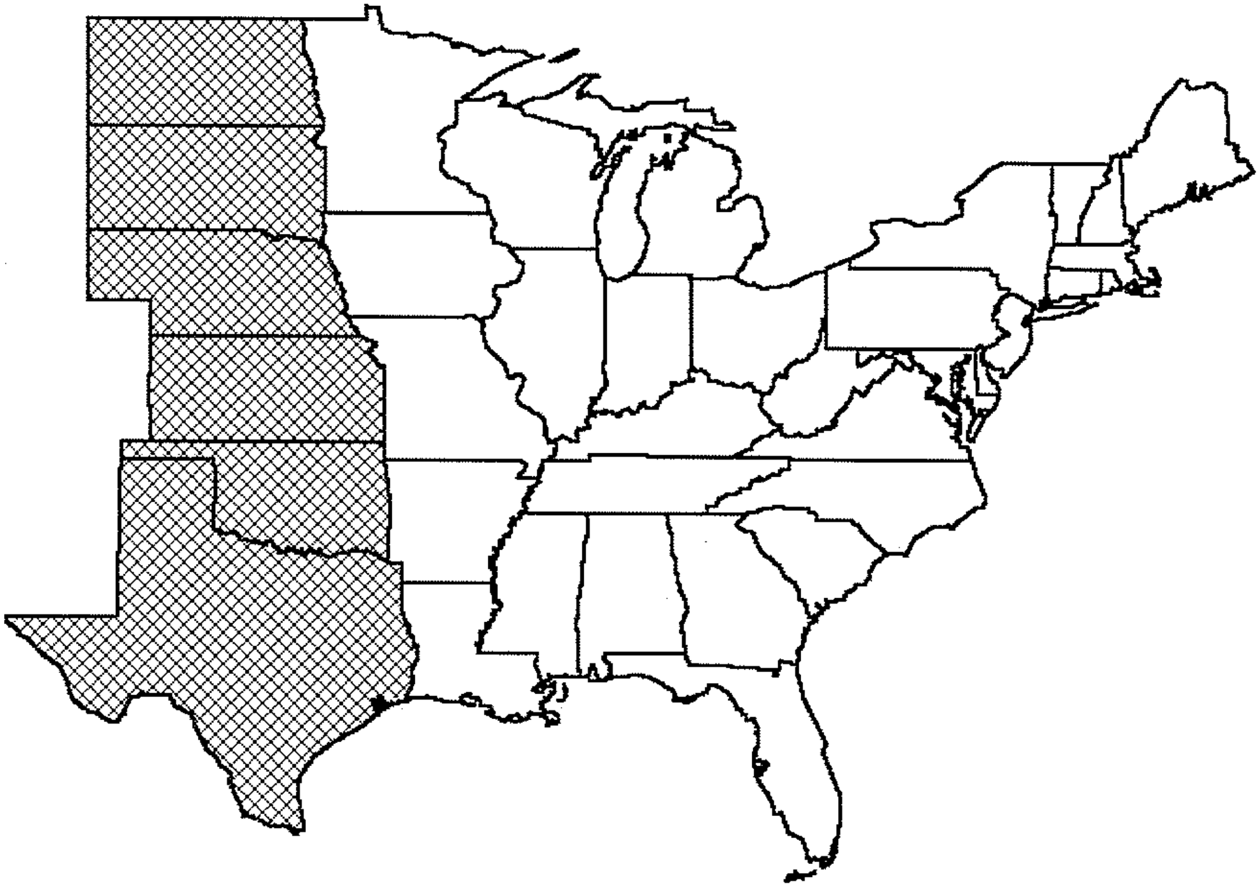
[7] To calculate total particle mass of ammonium sulfate and ammonium nitrate, the anion concentrations of sulfate and nitrate are multiplied by 1.375 and 1.290 respectively.

[8] Natural and man-made fugitive dust emissions account for 86% of PM_{10} emissions and 59% of $PM_{2.5}$ emissions in the most recent 1990 estimates in the National Emission Trends Inventory.

Figure 3-3

S-R Matrix

Air Quality Modeling Domain



*Buffer states are shaded--emissions are included for these states, but air quality concentrations are not calculated for these states.

To address this bias, a multiplicative factor of 0.25 is applied nationally to fugitive dust emissions as a reasonable first-order attempt to reconcile differences between modeled predictions of $PM_{2.5}$ and actual ambient data. This is the same adjustment that was used in the 1997 PM NAAQS RIA. A 0.25 multiplicative adjustment results in a fugitive dust contribution to modeled ambient $PM_{2.5}$ concentrations of 10% to 17%.[9] Even after this adjustment the fugitive dust fraction of total eastern $PM_{2.5}$ mass is 10.4%, which is still greater than the 5% indicated by IMPROVE monitors. However, given that the 0.25 multiplicative factor appears to bring the modeled fugitive dust contribution to $PM_{2.5}$ mass more within the range of values reported from speciated monitoring data, the fugitive dust contribution to total PM that is estimated by the S-R Matrix is adjusted by this factor. Since this factor still may result in an overprediction of the fugitive dust contribution, the S-R Matrix may tend to underpredict the effectiveness of strategies that affect NSA.

3.3.4 Normalizing S-R Matrix Results to Measured Data

In an attempt to further ensure comparability between S-R Matrix results and measured annual average PM values, the S-R results are calibrated using factors developed for the PM and Ozone NAAQS RIA (U.S. EPA, 1997a). For the NAAQS RIA, a "normalization factor" was developed for each Tier 1 to Tier 3 monitored county[10]. Nonmonitored counties were calibrated using the appropriate regional normalization factor calculated as the average of Tier 1 normalization factors across a given modeling region. The normalization factor was calculated as the monitored value divided by the modeled value.

All S-R Matrix predictions were normalized regardless of overprediction or underprediction relative to monitored values. This factor was applied equally across all particle species contributing to the annual average PM value at a county-level receptor.

The calibration procedure was conducted employing 1993 - 1995 PM_{10} ambient monitoring data from the AIRS database following the air quality tier data completeness parameters discussed above. The PM_{10} data represent the annual average of design value monitors averaged over three years (U.S.

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[9] See U.S. EPA, 1997b, page 6-5 for a map delineating modeling regions. Using 0.25 multiplicative factor, fugitive dust as percentage of $PM_{2.5}$ mass for: Central U.S. = 17.2%; Eastern U.S.= 10.4%; Western U.S.= 10.6%. By comparison, without using a multiplicative factor, fugitive dust as a percentage of $PM_{2.5}$ mass for: Central U.S. = 44.6%; Eastern U.S. = 30.9%; Western U.S. = 31.5%.

[10] The normalization procedure was conducted for county-level modeled PM_{10} and $PM_{2.5}$ estimates falling into one of four air quality data tiers. The tiering scheme reflects increasing relaxation of data completeness criteria and therefore increasing uncertainty for the annual design value (U.S. EPA, 1997f). Nationwide, Tier 1 monitored counties cover the 504 counties with at least 50% data completeness and therefore have the highest level of certainty associated with the annual design value. Tier 2 monitored counties cover 100 additional counties with at least one data point (i.e., one 24-hour value) for each of the three years during the period 1993 -1995. Tier 3 monitored counties cover 107 additional counties with missing monitoring data for one or two of the three years 1993 - 1995. In total, Tiers 1, 2 and 3 cover 711 counties currently monitored for PM_{10} in the 48 contiguous states. In 1997 the PM_{10} monitoring network consisted of approximately 1600 individual monitors with a coverage of approximately 711 counties in the 48 contiguous states. Tier 4 covers the remaining 2369 nonmonitored counties.

EPA, 1997d). The standardization for temperature and pressure was eliminated from this concentration data based upon proposed revisions to the reference method for PM_{10}.[11]

Because there is little $PM_{2.5}$ monitoring data available, a general linear model was developed to predict $PM_{2.5}$ concentrations directly from the 1993 - 1995 PM_{10} values (U.S. EPA, 1996b). A SAS™ general linear model (i.e., GLM) procedure was used to predict $PM_{2.5}$ values (dependent variable) as a function of independent variables for season, region, and measured PM_{10} value. These derived $PM_{2.5}$ data were used to calibrate model predictions of annual average $PM_{2.5}$.

3.3.5 Development of Annual Median $PM_{2.5}$ Concentrations

The CRDM procedure does not directly produce estimates of daily 24-hour average PM concentrations or annual median PM concentrations. Some health benefits have concentration-response functions that rely on estimates of either the daily 24-hour average or annual median concentrations. Using historical data, EPA developed 24-hour average estimates corresponding to the 99th percentile value for PM_{10} and the 98th percentile value for $PM_{2.5}$ reflecting forms of PM_{10} and $PM_{2.5}$ daily standards.

Peak-to-mean ratios (i.e., ratio of the 24-hour averge value to annual average value) are established from actual PM_{10} monitor data for 1993 to 1995 from Tier 1 through Tier 3 monitored counties. For PM_{10}, the peak value is defined exactly the way it is for the new PM_{10} NAAQS, i.e., the value corresponding to the 99th percentile value of the distribution of actual daily 24-hour average PM_{10} values. For $PM_{2.5}$, the peak value is also defined exactly the way it is for the new $PM_{2.5}$ NAAQS, i.e., the value corresponding to the 98th percentile value of the distribution of estimated daily 24-hour average $PM_{2.5}$ values. These historical peak-to-mean ratios for each monitored county are assumed to hold for the 2007 model year in this analysis and are applied to the annual average PM estimates generated by the S-R Matrix. Peak values in nonmonitored counties are estimated using the regional average peak-to-mean ratios in Tier 1 monitored counties.

Starting with the annual mean and peak values developed from the S-R Matrix, maximum likelihood is then used to estimate the parameters of a Gamma distribution that are most consistent with the S-R Matrix results. The parameters of the Gamma distribution are then used to estimate the annual median concentration and the concentration corresponding to each decile of the distribution.

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[11] See Appendix J - Reference Method for PM_{10}, Final Rule for National Ambient Air Quality Standards for Particulate Matter (Federal Register, Vol. 62, No. 138, p. 41, July 18, 1997).

3.3.6 S-R Matrix PM Air Quality Results

Table 3-3 provides a summary of the predicted ambient PM_{10} and $PM_{2.5}$ concentrations used in this study. Similar to the results using the RPM approach, the concentration changes are generally very small. For the 0.15 option, annual mean PM_{10} changes range from an increase of 0.26 µg/m^3 to a decrease of -0.57 µg/m^3, with an average annual mean change across the 31 state domain of -0.04 µg/m^3. Therefore, the absolute changes in PM occur within a slightly wider band than with the RPM, and the average annual mean change is slightly lower (-0.04 µg/m^3 versus -0.06 µg/m^3).

Table 3-3
Summary of S-R Matrix Derived PM Air Quality

		Change Relative To 2007 Base Case [a]				
Statistic	**2007 Base Case**	**0.25 Trading**	**0.20 Trading**	**Reg. 1**	**0.15 Trading**	**0.12 Trading**
Minimum Annual Mean PM_{10} (µg/m^3) [b]	5.39	-0.56	-0.56	-0.53	-0.57	-0.67
Maximum Annual Mean PM_{10} (µg/m^3) [b]	66.37	0.20	0.21	0.26	0.26	0.16
Average Annual Mean PM_{10} (µg/m^3)	22.62	-0.03	-0.03	-0.02	-0.04	-0.06
Population-Weighted Average Annual Mean PM_{10} (person-µg/m^3) [c]	25.96	-0.03	-0.04	-0.03	-0.04	-0.07
Minimum Annual Mean $PM_{2.5}$ (µg/m^3) [b]	3.49	-0.52	-0.52	-0.49	-0.53	-0.67
Maximum Annual Mean $PM_{2.5}$ (µg/m^3) [b]	27.63	0.20	0.21	0.25	0.26	0.17
Average Annual Mean $PM_{2.5}$ (µg/m^3)	10.74	-0.03	-0.03	-0.02	-0.04	-0.05
Population-Weighted Average Annual Mean $PM_{2.5}$ (person-µg/m^3) [c]	12.62	-0.03	-0.04	-0.03	-0.04	-0.06

[a] The change is defined as the control case value minus the base case value.

[b] The base case minimum (maximum) is the value for the county with the lowest (highest) annual average. The change relative to the base case picks the minimum (maximum) from the set of changes in all counties.

[c] Calculated by summing the product of the projected 2007 county population and the estimated 2007 county PM concentration, and then dividing by the total population in the 31 states modeled using the S-R Matrix

Population-weighted air quality changes were not estimated using the S-R Matrix results. The results generated from the RPM modeling shown in Appendix B should be generally representative of the direction and magnitude of changes that would be estimated using the S-R Matrix results.

The air quality technical support document for this RIA (Abt Associates, 1998) contains maps showing the base case PM concentrations and PM concentration changes generated using the S-R Matrix for each of five regulatory alternatives (0.25 Trading, 0.20 Trading, Regionality 1, 0.15 Trading, and 0.12 Trading). Similar maps can also be found in Pechan, 1998.

3.4 Nitrogen Deposition Estimates

Nitrogen deposition estimates are generated using RADM. The RADM was developed over a ten year period, 1984 - 1993, under the auspices of the National Acid Precipitation Assessment Program to address policy and technical issues associated with acidic deposition. The model is designed to provide a scientific basis for predicting changes in deposition and air quality resulting from changes in precursor emissions and to predict the levels of acidic deposition in certain sensitive receptor regions. To do so requires that RADM be a multipollutant model that predicts the oxidizing capacity of the atmosphere, including the prediction of ozone, and chemical transformations involving oxides of sulfur and nitrogen.

The development, application, and evaluation of the RADM has been documented extensively by NAPAP (Chang, et al. 1987 & 1990; Dennis et al. 1990). RADM has been used in several recent studies of acidic deposition, including EPA's 1995 *Acid Deposition Standard Feasibility Study Report to Congress* (U.S. EPA, 1995), EPA's 1997 *Deposition of Air Pollutants to the Great Waters* Report to Congress (U.S. EPA, 1997e), and in work estmating the nitrogen deposition airshed of the Chesapeake Bay watershed (Dennis, 1997).

RADM estimates deposition in units of kilograms per hectare (kg/ha). Wet deposition is estimated in the form of SO_4^{2-}, NO_3^-, NH_3, H^+. Dry deposition is estimated in the form of SO_2, SO_4 as aerosol, O_3, HNO_3, NO_2, H_2O_2. The deposition estimates are mapped to specific East Coast and Gulf Coast estuaries and their watersheds[12]. Land deposited nitrogen in each watershed is multiplied by a factor of 10% to obtain the nitrogen load delivered via export (pass-through) to the corresponding estuary.

Table 3-4 provides a summary of the nitrogen deposition estimates for each cell in the RADM domain. The changes range from 0.01 kg/ha to 3.66 kg/ha. The results for the 0.15 option represent an 11% reduction in the average annual deposition across the entire domain. The air quality technical support document for this RIA (Abt Associates, 1998) contains maps showing the nitrogen deposition changes generated using RADM for each of five regulatory alternatives (0.25 Trading, 0.20 Trading, Regionality 1, 0.15 Trading, and 0.12 Trading). Another technical support document for this RIA (EPA, 1998d) contains additional information on the reduction in nitrogen loads to 12 study set estuaries.

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[12] EPA has developed a methodology to assess nitrogen deposition benefits directly for 12 different estuaries: Albemarle/ Pamlico Sounds, Cape Cod Bay, Chesapeake Bay, Delaware Bay, Delaware Inland Bays, Gardiners Bay, Hudson R./ Raritan Bay, Long Island Sound, Massachusetts Bay, Narragansett Bay, Sarasota Bay, and Tampa Bay.

Table 3-4
Summary of 2007 Nitrogen Deposition in RADM Domain

Statistic	2007 Base Case	Change Relative To 2007 Base Case				
		0.25 Trading	0.20 Trading	Reg. 1	0.15 Trading	0.12 Trading
Minimum Annual Deposition (kg/ha)	0.74	0.00	0.00	-0.01	-0.01	-0.01
Maximum Annual Deposition (kg/ha)	31.91	-2.62	-3.19	-3.22	-3.58	-3.66
Average Annual Deposition (kg/ha)	4.83	-0.33	-0.47	-0.50	-0.55	-0.57

3.5 Visibility Degradation Estimates Using RPM and the S-R Matrix

Visibility degradation is often directly proportional to decreases in light transmittance in the atmosphere. Light transmittance is attenuated by scattering and absorption by both gases and particles. The light-extinction coefficient is a measure of the total fraction of light that is attenuated per unit distance (Sisler, 1996):

$$b_{ext} = b_{Ray} + b_{sp} + b_{ag} + b_{abs}$$

where:

b_{ext} = total light extinction coefficient (1/Mm),
b_{Ray} = light extinction coefficient due to natural Rayleigh scatter (1/Mm),
b_{sp} = light extinction coefficient due to scattering by particles (1/Mm),
b_{ag} = light extinction coefficient due to absorption by gases (1/Mm), and
b_{abs} = light extinction coefficient due to absorption by particles (1/Mm).

The light extinction coefficient is calculated by multiplying the concentration of aerosol species and particles species by their corresponding light-extinction efficiency, and summing over all species.

The term b_{sp} can be broken into the various species of fine and coarse particles that scatter light. Because fine particles are much more efficient at light scattering than coarse particles, several fine particle species are specified, whereas coarse particles are kept as one category. Fine particles with significant light-extinction efficiencies include sulfates, nitrates, organic carbon, elemental carbon (soot), and soil (Sisler, 1996).

Once the light-extinction coefficient is determined, the visibility index called deciview (*dv*) can be calculated (Sisler, 1996):

$$dv = 10 \cdot \ln(b_{ext} \cdot 10^{-3} / 0.01\, km^{-1})$$

where:

10^{-3} = constant to convert Mm^{-1} to km^{-1}.

A change of one deciview represents a change of approximately ten percent in b_{ext}, "which is a small but perceptible scenic change under many circumstances" (Sisler, 1996, p.1-7).

Visibility degradation estimates in "recreational" (e.g., federally designated Class I areas such as national parks and recreation areas) and "residential" (non-Class I areas) areas are generated using the results of both RPM and the S-R Matrix. RPM computes the light extinction due to the combined scattering of light by sulfates, nitrates, and organics which are part of the b_{sp} term of the extinction equation. RPM does not include the soil part of b_{sp}, but it does indirectly account for the soot part through a slight modification of the index of refraction for particles. RPM does not include gas absorption (by NO_2) because it is quite small. Rayleigh scattering is accounted for in RPM's calculation of deciview, because Rayleigh is taken as the "floor" for deciview; however, Rayleigh scattering is not in RPM's calculation of b_{ext}. Therefore, RPM estimates underpredict total light extinction. A correction for this underprediction is discussed in Chapter 4, section 4.4.5.

The S-R Matrix results are also used to estimate county-level light extinction. The recreational visibility calculations use the full set of parameters in the extinction equation, due to the availability of data from IMPROVE monitors, while the residential visibility calculations use county-level sulfate, nitrate and coarse particle estimates. Using less than the full set of terms in the residential visibility calculations leads to an underestimate of light extinction, and as noted for RPM a correction for this underprediction is presented in Chapter 4, section 4.4.5.

The visibility benefits analysis (see Chapter 4) distinguishes between general regional visibility degradation and visibility degradation in certain Federally-designated Class I areas (i.e., national parks, forests, recreation areas, wilderness areas, etc.). Therefore visibility degradation estimates are separated into "residential" and "recreational" categories depending upon the geographic area covered by the estimate.

Table 3-5 provides a summary of the visibility degradation estimates derived both from the RPM and the S-R Matrix results in terms of deciviews. The valuation methodology for recreational visibility requires separate treatment of visibility changes in Class I areas in the Southeast region versus Class I areas in the Central and Northeast regions. Table 3-5 provides visibility degradation estimates for both regions. All predicted visibility changes are small, with the largest residential changes occuring the the Southeast region. The S-R Matrix predictions are similar to the RPM predictions in the Southeast for each alternative except 0.12 trading, but are slightly smaller than the RPM predictions in the Central and Northeast regions.

Table 3-5
Summary of 2007 Visibility Degradation Estimates
(deciviews)

Visibility Degradation	**2007 Base Case [a]**	**Change Relative To 2007 Base Case [b]**				
		0.25 Trading	**0.20 Trading**	**Reg. 1**	**0.15 Trading**	**0.12 Trading**
***Southeast* [e]**						
RPM Annual Average--Residential	21.87	-0.07	-0.08	-0.07	-0.11	-0.22
RPM Annual Average--Recreational [c]	20.27	-0.12	-0.16	-0.16	-0.15	-0.24
S-R Matrix Annual Average--Residential	20.13	-0.08	-0.08	-0.07	-0.10	-0.12
S-R Matrix Annual Average--Recreational [c]	23.06	-0.07	-0.07	-0.06	-0.08	-0.09
***Central & Northeast* [e]**						
RPM Annual Average--Residential	17.12	-0.02	-0.04	-0.03	-0.03	-0.09
RPM Annual Average--Recreational [d]	15.87	-0.01	-0.03	-0.03	-0.06	-0.10
S-R Matrix Annual Average--Residential	18.77	-0.02	-0.01	0.00	-0.02	-0.05
S-R Matrix Annual Average--Recreational [d]	19.39	0.02	0.02	0.02	0.02	-0.01

[a] The RPM only accounts for visibility degradation due to sulfates and nitrates, but not other variables such as coarse PM and organic matter. This leads RPM to *underestimate* total residential and recreational visibility degradation. However, the absolute change from the base case to the control options is essentially correct since the change in sulfates and nitrates dominates the change in other variables affecting visibility. The S-R Matrix *recreational* estimates are correct since they include all visibility variables, but the S-R Matrix *residential* estimates only account for sulfates, nitrates, and coarse PM, and thus underestimate total residential visibility. As with RPM, the S-R matrix correctly estimates the change in visibility from the base case to the control options. The effect of underestimating visibility on the dollar value of visibility change is discussed in Chapter 11.

[b] The change is defined as the control case deciview level minus the base case deciview level.

[c] The four Southeastern national parks are: Shenandoah, Mammoth Cave, Great Smoky Mountains, and the Everlglades.

[d] The three Central and Northeastern national parks are: Voyageurs, Isle Royale, and Acadia.

[e] The Southeast region includes the following 12 states plus Washington D.C.: AL, DE, FL, GA, KY, MD, MS, NC, SC, TN, VA, WV. The remaining states in the 37 state OTAG region comprise the Central and Northeast regions.

Table 3-6 presents changes in the population-weighted visibility degradation estimates from the RPM in terms of annual mean extinction. As shown, the change is much less than 1% for each alternative except 0.12 trading.

Table 3-6
2007 Population-Weighted Sum of Annual Mean Extinction:
RPM Results

Percent Change from Base Case				
0.25 Trading	**0.20 Trading**	**Regionality 1**	**0.15 Trading**	**0.12 Trading**
-0.3	-0.4	-0.4	-0.3	-1.3

The air quality technical support document for this RIA (Abt Associates, 1998) contains maps showing the base case visibility degradation and visibility degradation changes generated using both RPM and the S-R Matrix for each of five regulatory alternatives (0.25 Trading, 0.20 Trading, Regionality 1, 0.15 Trading, and 0.12 Trading). Maps showing visibility degradation changes for selected Class I areas can also be found in Pechan, 1998.

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Chapter 4. BENEFITS OF REGIONAL NOx REDUCTIONS

The changes in ozone and PM ambient concentrations described in Chapter 3 will result in changes in the physical damages associated with elevated ambient concentrations of these pollutants. The damages include changes in both human health and welfare effects categories.

This chapter presents the methods used to estimate the physical and monetary benefits of the modeled NOx and SO_2 emissions changes from implementing the revised SIPs, the estimates of the avoided physical damages (e.g., incidence reductions), and the results of the benefits analysis for a range of regulatory alternatives considered for the SIP call. EPA decided to analyze the benefits of the most significant alternatives that it considered for determining state NOx budgets for the electric power industry and other stationary sources. The five alternatives are described in Table 2-3 in Chapter 2 of Volume 2 of the RIA. In order to conserve analytical resources, the benefits of Regionality 2 are not analyzed. Regionality 2 achieves emission reductions and air quality improvements that are similar, though not identical, to Regionality 1 and 0.15 Trading. It is likely that total benefits for Regionality 2 would fall somewhere in between the benefits estimates for Regionality 1 and 0.15 Trading.

The remainder of this chapter is laid out as follows. Section 4.1 provides an overview of the benefits methodology. Section 4.2 discusses issues in estimating health effects. Sections 4.3 discusses methods and provides estimated values for avoided incidences and monetary benefits for ozone and PM related health effects. Section 4.4 discusses methods and provides estimated values for ozone and PM related welfare effects. Section 4.5 provides estimates of total health and welfare benefits associated with alternative NOx emission limit policies. Finally, Section 4.6 discusses potential benefit categories that are not quantified due to data and/or methodological limitations, and provides a list of analytical uncertainties, limitations, and biases.

4.1 Overview of Benefits Estimation

Most of the specific methods and information used in this benefit analysis are similar to those used in the §812 Retrospective of the Benefits and Costs of the Clean Air Act and forthcoming §812 Prospective EPA Reports to Congress, which were reviewed by EPA's Science Advisory Board (EPA, 1997c),as well as the approach used by EPA in support of revising the ozone and PM NAAQS in 1997 (EPA, 1997a and 1997b).

Prior to describing the details of the approach for the benefits analysis, it is useful to provide an overview of the approach. The overview is intended to help the reader better identify the role of each issue described later in this chapter.

The general term "benefits" refers to any and all outcomes of the regulation that are considered positive; that is, that contribute to an enhanced level of social welfare. The economist's meaning of "benefits" refers to the dollar value associated with all the expected positive impacts of the regulation; that is, all regulatory outcomes that lead to higher social welfare. If the benefits are associated with market goods and services, the monetary value of the benefits is approximated by the sum of the predicted changes in "consumer (and producer) surplus." These "surplus" measures are standard and widely accepted measures in the field of applied welfare economics, and reflect the degree of well being enjoyed by people given different levels of goods and prices. If the benefits are non-market benefits (such as the risk reductions associated with environmental quality improvements), however, other methods of measuring benefits must be used. In contrast to market goods, non-market goods such as environmental quality improvements are public goods, whose benefits are shared by many people. The total value of such a good is the sum of the dollar amounts that all those who benefit are willing to pay.

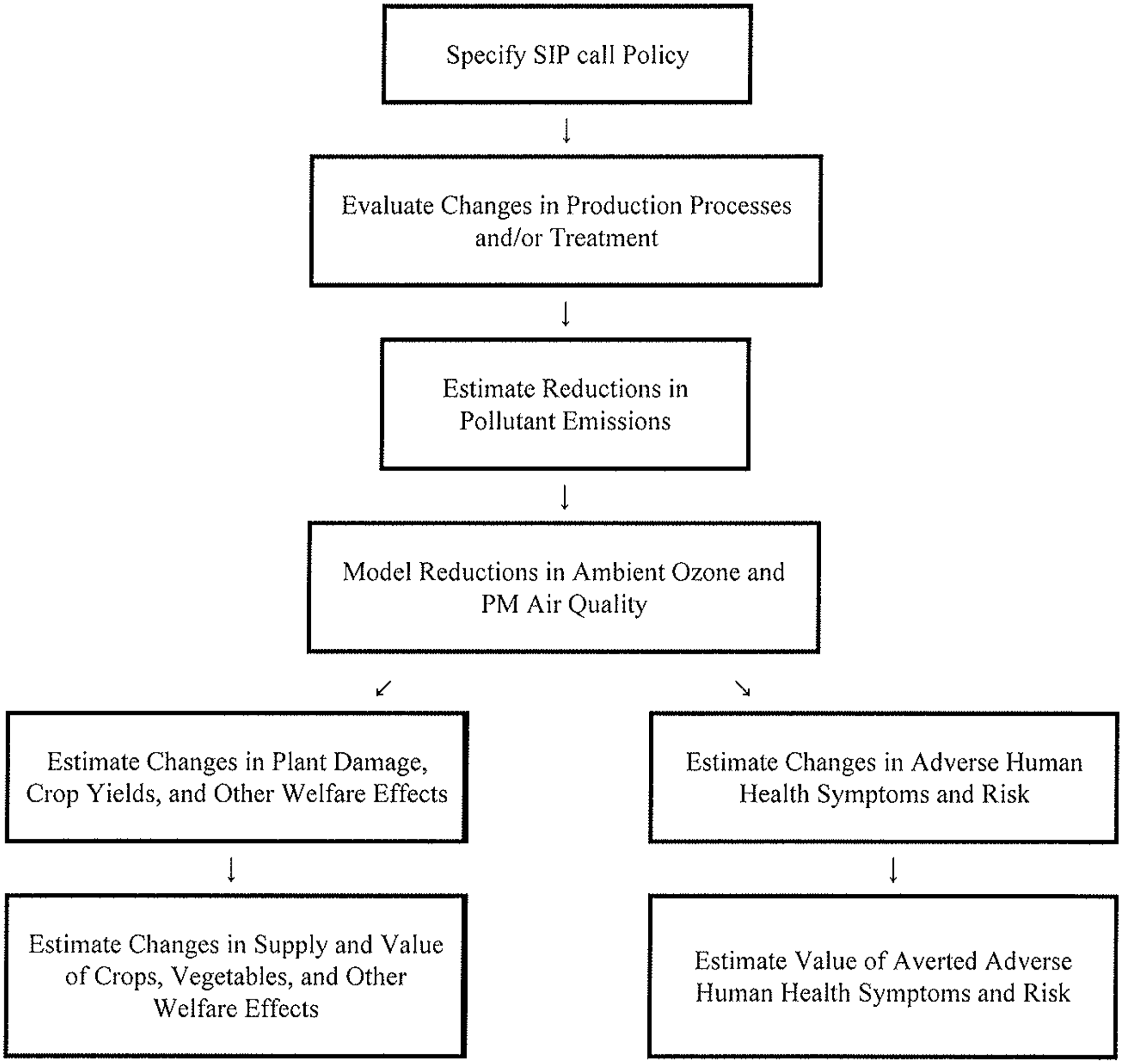
In addition to benefits, regulatory actions may also lead to potential disbenefits, i.e. outcomes that have a negative impact on social welfare. In general these disbenefits will be incidental to the stated goals of the regulation, otherwise (in an efficient regulatory environment) the regulation would not have been promulgated. In order to fully quantify the benefits and costs of a regulatory action, both the benefits and disbenefits should be calculated, so that net benefits (equal to benefits minus disbenefits minus costs) will not be biased upwards. In many cases, however, disbenefits are difficult to quantify, as it is often unclear where and how disbenefits will occur. Benefits may also be difficult to quantify, since many benefits are not measurable using market based measures.

This conceptual economic foundation raises several relevant issues and potential limitations for the benefits analysis of the regulation. First, the standard economic approach to estimating environmental benefits is anthropocentric -- all benefits values arise from how environmental changes are perceived and valued by people in present-day values. Thus, all near-term as well as temporally distant future physical outcomes associated with reduced pollutant loadings need to be predicted and then translated into the framework of present-day human activities and concerns. Second, as noted below, it is not possible to quantify or to value all of the benefits resulting from environmental quality improvements.

Conducting a benefits analysis for anticipated changes in air emissions is a challenging exercise. Assessing the benefits of a regulatory action requires a chain of events to be specified and understood. As shown in Figure 4-1, illustrating the causality for air quality related benefits, the estimation of benefits requires information about: (1) institutional relationships and policy-making; (2) the technical feasibility of pollution abatement; (3) the physical-chemical properties of air pollutants and their consequent linkages to biological or ecological responses in the environment, and (4) human responses and values associated with these changes.

The first two steps of Figure 4-1 reflect the institutional and technical aspects of implementing the NOx SIP call regulation (the improved process changes or pollutant abatement). The estimated changes in ambient PM or ozone concentrations are directly linked to the estimated changes in precursor pollutant emission reductions through the use of air quality modeling, as described in Chapter 10.

Figure 4-1 Example Methodology of a Benefits Analysis



A "damage function" approach is used to estimate the adverse physical effects from air pollution that will be avoided in the eastern United States due to implementation of the emission reductions required by the NOx SIP call (the exception to this is the estimation of nitrogen deposition benefits, which uses an avoided cost approach). An "economic unit value" approach is used (for most effect categories, e.g., premature mortality or chronic bronchitis) to estimate society's aggregate demand (i.e., willingness to pay) for avoiding each type of physical effect on a per incidence level. Total value for a given physical effect is simply the product of the number of incidences avoided and the value per incidence avoided. All dollar estimates of monetary benefits presented in this chapter are in 1990 dollars.

The valuation of avoided incidences of health effects and avoided degradation of welfare effects relies on benefits transfer. The benefits transfer approach takes values or value functions generated by previous research and transfers them from the study to the policy of interest. For example, the value of reduced mortality is obtained from a distribution of values of statistical life based on 26 wage-risk and contingent valuation studies. None of the values for the health and welfare categories valued in this benefit analysis were generated specifically in the context of the NOx SIP call.

The first step in a benefits analysis using this approach is the identification of the types or categories of benefits associated with the anticipated changes in ambient air quality conditions. The second step is the identification of relevant studies examining the relationships between air quality and these benefit categories and studies estimating the value of avoiding damages. Table 4-1 provides an example of the types of benefits potentially observed as a result of changes in air quality. The types of benefits identified in both the health and welfare categories can generally be classified as use benefits or non-use benefits.

Use benefits are the values associated with an individual's desire to avoid exposure to an environmental risk. Use benefits include both direct and indirect uses of affected ambient air, and embrace both consumptive and non-consumptive activities. In most applications to air pollution scenarios, the most prominent use benefits are those related to human health risk reductions, effects on crops and plant life, visibility, and materials damage.

Non-use (intrinsic) benefits are values an individual may have for lowering air pollution concentrations or the level of risk unrelated to his or her own exposure. Individuals apart from any past, present, or anticipated future use of the resource in question can value improved environmental quality. Such non-use values may comprise a significant portion of the total monetary benefits. However, the dollar amount to assign to these non-use values often is a matter of considerable debate. While human uses of a resource can be observed directly and valued with a range of technical economic techniques, non-use values must be ascertained through indirect methods, such as asking survey respondents to reveal their values.

Table 4-1
Examples of Potential Benefits of Air Quality Improvements

USE BENEFITS	**EXAMPLES**
Direct	Human Health Improvements (e.g., less incidences of coughing) Increased Crop Yields
Indirect	Non-Consumptive Use (e.g., improved visibility for recreational activities)
Option Value	Risk Premium for Uncertain Future Demand Risk Premium for Uncertain Future Supply (e.g., treating as insurance, the protection of a forest just in case a new use for a forest product will be discovered in the future)
Aesthetic	Residing, working, traveling, and/or owning property in reduced smog locations
NON-USE BENEFITS	
Bequest	Intergenerational Equity (e.g., an older generation wanting a younger generation to inherit a protected environment)
Existence	Stewardship/Preservation/Altruistic Values (e.g., individuals wanting to protect a forest even if they know that they will never use the forest) Ecological Benefits

Non-use values may be related to the desire that a clean environment be available for the use of others now and in the future, or may be related to the desire to know that the resource is being preserved for its own sake, regardless of human use. The component of non-use value that is related to the use of the resource by others in the future is referred to as the bequest value. This value is typically thought of as altruistic in nature. For example, the value that an individual places on reducing the general population's risk of PM and/or ozone exposure either now or in the future is referred to as the bequest value. Another potential component of non-use value is the value that is related to preservation of the resource for its own sake, even if there is no human use of the resource. This component of non-use value is sometimes referred to as existence value. An example of an existence value is the value placed on protecting the habitats of endangered species from the effects of air pollution, even if the species have no direct use to humans.

The majority of health and welfare benefits categories included in this analysis can be classified as direct use benefits. These benefits are discussed in greater detail than other benefits categories presented in Table 4-1 because more scientific and economic information has been gathered for the direct use benefits category. Detailed scientific and economic information is not as readily available for the remainder of the potential benefits categories listed in Table 4-1. Information pertaining to indirect use, option value, aesthetic, bequest, and existence benefits is often more difficult to collect. For example, lowering ambient ozone concentrations in an area is expected to reduce physical damage to ornamental plants in the area. Homeowners living in the affected area with ornamental plants in their yards are expected to benefit from the reduced damage to their plants, with the plants possibly exhibiting an improved appearance or experiencing an extended life. Although scientific information can help identify the benefits category of decreased damage to urban ornamentals, lack of more detailed scientific and economic information (e.g., exposure-response relationships for urban ornamentals and values associated with specific types of injuries and mitigation) currently prevents quantification of this benefits category.

It is also difficult to identify all the types of benefits that might result from environmental regulation and to value those benefits that are identified. A cost analysis is expected to provide a more comprehensive estimate of the cost of an environmental regulation because technical information is available for identifying the technologies that would be necessary to achieve the desired pollution reduction. In addition, market or economic information is available for the many components of a cost analysis (e.g., energy prices, pollution control equipment, etc.). A similar situation typically does not exist for estimating the benefits of environmental regulation. This problem is due to the non-market nature of many benefits categories. Since many pollution effects (e.g., adverse health or ecological effects) traditionally have not been traded as market commodities, economists and analysts cannot look to changes in market prices and quantities to estimate the value of these effects. This lack of observable markets may lead to the omission of significant benefits categories from an environmental benefits analysis. Likewise, difficulties in measuring disbenefits may lead to a positive bias in net benefits. The net result of underestimating benefits and disbenefits will depend on how completely each category is measured.

Because of the inability to quantify many of the benefits categories listed in Table 4-1, as well as the omission of unknown but relevant environmental benefits categories, the quantified benefits presented in this report may underestimate total benefits. It is not possible to quantify the magnitude of this underestimation. The more important of these omitted effect categories are shown in Table 4-2. Underestimation of total benefits may be mitigated to some extent if there are also relevant disbenefit categories that are omitted or unquantified.

Within each effect category, there may be several possible estimates of health and welfare effects or monetary benefit values. Each of these possibilities represents a health or welfare "endpoint." The basic structure of the method used to conduct the benefits analysis is to create a set of benefit estimates reflecting different key assumptions concerning environmental conditions and the responsiveness of human health and the environment to changes in air quality. Total benefits are presented as a plausible range representing the sensitivity of benefits over the set of maintained assumptions. The upper and lower ends of the plausible range of total benefits are constructed using estimates of non-overlapping endpoints for each effect category, selected to avoid double counting. Double counting occurs when two endpoints contain values for the same thing. For example, an endpoint measuring avoided incidences of all hospital admissions would incorporate avoided incidences of hospital admissions just for heart disease. Thus including values for avoiding both types of hospital admissions would double count the value of avoided hospital admissions for heart disease. The upper and lower ends of the plausible range do not necessarily represent the sum of the highest values for each endpoint. Instead, they represent the points associated with the combinations of assumptions that are expected to generate the lowest and highest benefit estimates for the majority of regulatory alternatives. The plausible range does not provide information on the likelihood of any set of assumptions being the correct one. Thus, while the plausible range indicates the sensitivity of benefits to the various assumptions, it requires a subjective determination of which assumption set most closely represents reality.

Table 4-2
Unquantified Benefit Categories*

	Unquantified Benefit Categories Associated with Ozone and Nitrogen Oxides	Unquantified Benefit Categories Associated with PM
Health Categories	Airway responsiveness Pulmonary inflammation Increased susceptibility to respiratory infection Acute inflammation and respiratory cell damage Chronic respiratory damage/Premature aging of lungs Ultraviolet-B radiation (disbenefit)	Changes in pulmonary function Morphological changes Altered host defense mechanisms Cancer Other chronic respiratory disease
Welfare Categories	Ecosystem and vegetation effects in Class I areas (e.g., national parks) Damage to urban ornamentals (e.g.,grass, flowers, shrubs, and trees in urban areas) Fruit and vegetable crops Reduced yields of tree seedlings, commercial and non-commercial forests Damage to ecosystems Materials damage (other than consumer cleaning cost savings) Nitrates in drinking water Brown Clouds	Materials damage (other than consumer cleaning cost savings) Damage to ecosystems (e.g., acid sulfate deposition) Nitrates in drinking water Brown Clouds

* Note that there are other pollutants that are reduced in conjunction with strategies implemented to reduce NOx emissions for the SIP call. These include carbon (a pollutant associated with global climate change) and mercury (a toxic pollutant). These emission reductions are also not considered in this benefits analysis.

There are many subjective judgements that must be made in order to select the set of relationships and values for the benefits analysis. The specific selections used to develop the plausible range are designed to reflect the EPA's best current judgement on each issue, considering the state of current scientific knowledge, previous Agency analyses, and the most recent advice provided by EPA's Science Advisory Board on performing benefits analysis for criteria air pollution control programs. There are, however, defensible alternatives to virtually every decision about the makeup of the plausible range. In order better to inform the reader of important alternative assumptions that could have been made, and to provide an understanding of the impact of each alternative on the overall assessment of the monetary benefits, the benefits analysis includes a number of quantitative sensitivity analyses. Individual sensitivity analyses examine the effects of using alternative assumptions about individual choices incorporated in the benefits analysis, such as the impact of using short-term (daily) mortality functions instead of a long-term (chronic exposure) function.

Sensitivity analyses are also used to explore the impacts of including other endpoints, such as PM-related infant mortality, that are not as well understood as the effects included in the benefits analysis.

Sensitivity analyses will also be used to explore the effects of alternative valuation approaches, such as the use of alternative agricultural market simulation models.

A very important component in estimating PM-related health and welfare benefits is the characterization of air quality changes. Several models developed in recent years are capable of estimating PM_{10} concentrations, but have not been rigorously tested for estimating ambient concentrations of $PM_{2.5}$ because there is currently sparse monitoring of the data necessary to benchmark model performance. As indicated in Chapter 3, two air quality models, RADM-RPM and the Source-Receptor (S-R) Matrix, are used in this analysis to predict changes in ambient PM levels given changes in NOx and SO_2 emissions. The defining characteristics of each of these models are laid out in Chapter 3. It is not clear which of these models will better predict the Eastern U.S. atmosphere in the 2007 policy year. In order to reflect this uncertainty, the plausible range for individual PM-related health and welfare endpoints will incorporate estimates of avoided incidences and monetary benefits generated under each modeling framework.

Because of the nonlinear chemistry used by RADM-RPM to predict changes in $PM_{2.5}$, estimates of avoided incidences and associated monetary benefits may not follow a predictable pattern across regulatory alternatives. Previous experience with PM air quality models would suggest that benefits will increase as controls become more stringent, however, these models lacked or used incomplete characterizations of the role of NOx emissions in the production of oxidant fields that convert SO2 to acid sulfates, leading to a simplified characterization of the interactions between acid sulfates, nitrates, and ammonium. The role of NOx emissions in photochemistry can introduce non-linearities which, given the right set of atmospheric conditions, can result in situations where decreases in NOx can lead to increases in PM in some regions[1]. This can lead to smaller benefits for a more stringent regulatory alternative relative to a less stringent regulatory alternative (Dennis, 1998). This seems to be occurring in the 0.15 trading alternative, especially in the Northwest, Upper Midwest and Upper New England regions of the OTAG domain. In addition, implementation of specific control strategies, such as shifting of power generation and emissions trading under the Acid Rain Trading program can result in increases in SO_2 emissions in states outside the NOx SIP call region. In the 0.15 and 0.12 trading alternatives, significant shifts in power generation seem to be occuring between SIP call states and Gulf Coast states, leading to increases in both NOx and SO_2 emissions along the Gulf Coast, relative to the analysis baseline. Increases in PM in the Northeast and northwestern regions of the SIP call region seem to be caused by a combination of atmospheric chemistry and emissions trading, as well as transport of pollutants, especially in Pennsylvania and the upper New England area.

Because the modeled distributions of PM concentrations are non-normally distributed, the ordering effect is dependent on whether health effects are calculated using the median versus mean $PM_{2.5}$ concentration. The non-linearities in the air-chemistry change with movement from the lower tail to the upper tail of the distribution of PM concentrations. Non-linearities are more pronounced at the 50th percentile of the distribution than at the 90th percentile (Dennis, 1998). This can result in a greater degree of non-linearity in benefits results that are dependent on the median versus the mean. Implications of this for the SIP call benefits analysis are that relative to other endpoints, estimates of PM-related long-

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[1] See Chapter 3 Sections 3.3 and 3.4 for a more detailed discussion of the air quality models. See Appendix E for a more thorough discussion of the affect of non-linear chemistry on particle formation.

term mortalities, which are based on median $PM_{2.5}$ concentrations, are more sensitive to the non-linear chemistry effects between alternatives.

Throughout this benefits analysis, sensitivity analyses for assumptions affecting only a single endpoint and with no expected directional effect will be presented directly following the plausible range. These sensitivity analyses include short-term PM-related mortality, PM-related neo-natal mortality, alternative agricultural models, and an analysis of the effect of using only ozone mortality studies with a significant ozone coefficient to generate avoided ozone mortality incidences.

Table 4-3 lists the specific health and welfare effects that are included in the benefits analysis, indicating the specific effect categories that are included in the plausible range of benefits, as well as effects that are presented (or explored in greater detail) as quantified sensitivity analyses. Also included in Table 4-3 are the estimates of mean Willingness to Pay (WTP), or "unit values" used to monetize the benefits for each endpoint.

Table 4-3
Quantified and Monetized Health and Welfare Effects

Endpoint	Pollutant	Mean WTP per incident ($1990)
Health Effects in the Benefits Analysis		
Mortality, Long-term Exposure - Over age 30	$PM_{2.5}$	$4,800,000
Mortality, Short-term Exposure	Ozone	$4,800,000
Chronic Bronchitis - All Ages	PM_{10}	$260,000
Hospital Admissions - All Respiratory, All Ages	Ozone & $PM_{10}/PM_{2.5}$	$6,712 (Ozone) $6,344 (PM)
Hospital Admissions - Congestive heart failure	PM_{10}	$8,280
Hospital Admissions - Ischemic heart disease	PM_{10}	$10,308
Any of 19 Acute Respiratory Symptoms -Adult	Ozone	$18
Acute Bronchitis - Children	$PM_{10}/PM_{2.5}$	$45
Lower Respiratory Symptoms - Children	PM_{10}	$12
Upper Respiratory Symptoms - Children	PM_{10}	$19
Work Loss Days - Adult	$PM_{2.5}$	$83
Minor Restricted Activity Days (MRAD) - Adult	$PM_{2.5}$	$38
Welfare Effects in the Benefits Analysis		
Agriculture - Select Commodity Crops	Ozone	Direct Valuation
Household Soiling	PM_{10}	$2.52/household/$\mu g/m^3$ change in PM_{10}
Nitrogen Deposition in Estuarine and Coastal Waters	NOx	$105/kg of nitrogen
Decreased Worker Productivity	Ozone	$1/worker/10% change in Ozone
Visibility - Residential	Light Extinction[a]	$14/household/deciview
Visibility - Select Class I areas	Light Extinction[a]	$4/household/deciview

Endpoint	Pollutant	Mean WTP per incident ($1990)
Endpoints Presented as Sensitivity Analyses		
Mortality, Short-term Exp. -- Only significant studies	Ozone	$4,800,000
Mortality, Short-term Exp. - Over age 65	$PM_{2.5}$	$4,800,000
Post-Neonatal Mortality	PM_{10}	quantified but not monetized
Commercial Crops -- AGSIM model	NOx	$105/kg

[a] Measured in terms of deciview change.

4.2 Issues in Estimating Changes in Health Effects

This benefits analysis relies on concentration-response (C-R) functions estimated in published epidemiological studies relating adverse health and welfare effects to ambient air quality. The specific C-R functions used are included in Table 4-4.

When a single published study is selected as the basis of the C-R relationship between a pollutant and a given health endpoint, applying the C-R function is straightforward. This is the case for most of the endpoints selected for inclusion in the benefits analysis. A single C-R function may be chosen over other potential functions because the underlying epidemiological study used superior methods, data or techniques, or because the C-R function is more generalized and comprehensive. For example, the study that estimated the effects of PM on hospital admissions for all ages and all respiratory diseases is selected over studies limited to the over 65 year old population or specific categories of respiratory diseases.

The exceptions to the "single study" selection in the benefits analysis are mortality associated with exposure to ozone and chronic bronchitis associated with exposure to PM, which have multiple studies selected for use. Mortality associated with short-term exposure to $PM_{2.5}$, presented as a sensitivity analysis, is based on six C-R functions estimated in a single study. When several estimated C-R relationships between a pollutant and a given health endpoint have been selected, they are combined or pooled to derive a single estimate of the relationship. The details of the procedures used to combine multiple C-R functions are presented in a separate technical support document (Abt Associates, 1998a).

Whether the concentration-response relationship between a pollutant and a given health endpoint is estimated by a single function from a single study or by a pooled function of concentration-response functions from several studies, that same concentration-response relationship is applied everywhere in the benefits analysis. Although the concentration-response relationship may in fact vary somewhat from one location to another (for example, due to differences in population susceptibilities or differences in the composition of PM), location-specific concentration-response functions are generally not available. While a single function applied everywhere may result in overestimates of incidence changes in some locations and underestimates of incidence changes in other locations, these location-specific biases will to some extent cancel each other out when the total incidence change is calculated. It is not possible to know the extent or direction of the bias in the total incidence change based on application of a single C-R function everywhere.

The remainder of this section discusses two key issues involving the use of C-R functions to estimate the benefits of the NOx SIP call: baseline incidences and health effect thresholds, i.e. levels of pollution below which changes in air quality have no impacts on health.

4.2.1 Baseline Incidences

The epidemiological studies of the association between pollution levels and adverse health effects generally provide a direct estimate of the relationship of air quality changes to the relative risk of a health effect, rather than an estimate of the absolute number of avoided cases. For example, a typical result might be that a 10 $\mu g/m^3$ decrease in daily $PM_{2.5}$ levels might decrease hospital admissions by three percent. The baseline incidence of the health effect is necessary to convert this relative change into a number of cases.

United States county-level baseline mortality rates for 1990 were obtained from the National Center for Health Statistics (US Department of Health and Human Services, 1994). Because most PM and ozone studies that estimate C-R functions for mortality considered only non-accidental mortality, county-specific baseline mortality rates used in the estimation of PM- and ozone-related mortality were adjusted to provide a better estimate of county-specific non-accidental mortality. Each county-specific mortality rate was multiplied by the ratio of national non-accidental mortality to national total mortality (0.93).

Although total mortality incidences (over all ages) are available for counties, age-specific mortality incidences is not generally available at the county level. Therefore, county-specific baseline mortality incidences among individuals aged 30 and over (necessary for $PM_{2.5}$-related long-term exposure mortality, estimated by Pope et al., 1995) are estimated by applying national age-specific death rates to county-specific age distributions, and adjusting the resulting estimated age-specific incidences so that the estimated total incidences (including all ages) equals the actual county-specific total incidences.

Table 4-4
PM and Ozone Health and Welfare Concentration-Response Function Summary Data

Endpoint	Pollutant	Concentration-Response Function		Averaging Time		Population[a]	Pollutant Coefficient[b]
		Source	Functional Form	Studied	Applied		
Mortality							
Mortality (long-term exposure) -$PM_{2.5}$	$PM_{2.5}$	Pope et al., 1995	log-linear	annual median	annual median[c]	ages 30+	0.006408
Mortality (short-term exposure) -$PM_{2.5}$	$PM_{2.5}$	Schwartz et al., 1996a (6 cities)	log-linear	2-day average	1-day average	all	0.000782
Mortality (short-term exposure)	Ozone	Kinney, at al., 1995 (Los Angeles)	log-linear	daily 1-hour max	daily 1-hour max	all	0.000000
		Ito and Thurston, 1996 (Chicago)	log-linear	1-day average	1-day average	all	0.000677
		Moolgavkar, et al., 1995 (Philadelphia)	log-linear	1-day average	1-day average	all	0.000611
		Samet,et al., 1997 (Philadelphia)	log-linear	1-day average	1-day average	all	0.000936

Endpoint	Pollutant	Concentration-Response Function		Averaging Time		Population[a]	Pollutant Coefficient[b]
		Source	Functional Form	Studied	Applied		
Hospital Admissions							
All respiratory illnesses	$PM_{2.5}$/ PM_{10}	Thurston et al., 1994	linear	1-day average	1-day average	all	3.45 X 10^{-8}
Congestive heart failure	PM_{10}	Schwartz & Morris, 1995	log-linear	2-day average	1-day average	age 65+	0.00098
Ischemic heart disease	PM_{10}	Schwartz & Morris, 1995	log-linear	1-day average	1-day average	age 65+	0.00056
All respiratory illnesses	Ozone	Thurston et al., 1992	linear	daily 1-hour max	daily 1-hour max	all	0.00137
Respiratory Symptoms/Illnesses not requiring hospitalization							
Development of chronic bronchitis	PM_{10}	Schwartz, 1993		annual mean	annual mean	all	0.012
Acute bronchitis	$PM_{2.5}$/ PM_{10}	Dockery et al., 1989	logistic	annual mean	annual mean[d]	ages 10-12	0.0298
Upper respiratory symptoms (URS)	PM_{10}	Pope et al., 1991	log-linear	1-day average	1-day average	asthmatics, ages 9-11	0.0036
Lower respiratory symptoms (LRS)	PM_{10}	Schwartz et al., 1994	logistic	1-day average	1-day average	ages 8-12	0.01823
Any of 19 acute respiratory symptoms	Ozone	Krupnick et al., 1990	logistic	daily 1-hour max	daily 1-hour max	ages 18-65	0.00014
MRAD	$PM_{2.5}$	Ostro and Rothschild, 1989	log-linear	2-week average	1-day average	ages 18-65	0.00741
Work loss days (WLDs)	$PM_{2.5}$	Ostro, 1987	log-linear	2-week average	1-day average	ages 18-65	0.0046

Endpoint	Pollutant	Concentration-Response Function		Averaging Time		Population[a]	Pollutant Coefficient[b]
		Source	Functional Form	Studied	Applied		
Welfare Endpoints							
Decreased worker productivity	Ozone	Crocker & Horst, 1981 and EPA, 1994	percent change	1-day average	1-day average	laborers	n/a
Household soiling and damage	PM_{10}	ESEERCO, 1994	linear	annual mean	annual mean	all households	2.52 (dollars per μg/ m^3 PM10 per household)

[a] The population examined in the study and to which this analysis applies the reported concentration-response relationship. In general, epidemiological studies analyzed the concentration-response relationship for a specific age group (e.g., ages 65+) in a specific geographical area. This analysis applies the reported pollutant coefficient to all individuals in the age group nationwide.

[b] A single pollutant coefficient reported for several studies indicates a pooled analysis; see text for discussion of pooling concentration-response relationships across studies.

[c] All 1-day averages are 24-hour averages, 2-day averages are 48-hour averages, etc.

4.2.2 Thresholds

A very important issue in applied modeling of changes in ozone and PM is whether to apply the concentration-response functions to all predicted changes in ambient concentrations, even small changes occurring at levels approaching "anthropogenic background". Different assumptions about how to model thresholds can have a major effect on the resulting benefits estimates.

The Criteria Documents, Staff Papers and the Federal Register Notices promulgating the new ozone and PM standards conclude that there are no known threshold levels for any of the health effects to be included in the SIP call analysis (EPA, 1996c-1996f). For example, the Federal Register Notice promulgating the ozone standard included the following:

> The Administrator's consideration of an appropriate level for an 8-hour standard to protect public health with an adequate margin of safety necessarily reflects a recognition, as emphasized by CASAC, that it is likely that "O_3 may elicit a continuum of biological responses down to background concentrations" (Wolff, 1995b). Thus, in the absence of any discernible threshold, it is not possible to select a level below which absolutely no effects are likely to occur. Nor does it seem possible, in the Administrator's judgment, to identify a level at which it can be concluded with confidence that no "adverse" effects are likely to occur (Federal Register, Vol. 62, No. 138, p. 38863, July 18, 1997).

Similarly, the Administrator did not identify a PM threshold for the same reasons.

The underlying epidemiological functions used in most of the analysis are in fact continuous down to zero levels. However, in order to remain consistent with the available scientific information, the analysis does not model effects below certain levels. The approach used in the benefits analysis is identical to the approach used in the ozone and PM NAAQS RIA; individual concentration-response functions will not be applied to ambient concentrations occurring below the lowest observed levels reported by the authors of the underlying epidemiological studies. Where no lowest observed level was reported, the functions will be applied down to the "anthropogenic background" level. Theoretically, C-R functions should be reestimated when a threshold is assumed to insure consistency with the observed correlation between mortality incidences and the pollutant. If no threshold is assumed in the epidemiological study, then the slope of the C-R function will be flatter than for a function with a threshold. This reflects the fact that all of the observed changes in mortality would have to be associated with changes above the threshold, rather than being associated with changes along the full spectrum of pollutant concentrations. Unadjusted C-R functions are used in this benefits analysis due to a lack of availability of the underlying data used to estimate the C-R functions. These data are necessary to develop threshold adjusted C-R functions. Use of an unadjusted C-R function will result in an underestimate of total avoided incidences.

Because the issue of possible thresholds can have a major effect on the benefits estimation, estimates for individual benefit endpoints will be generated using alternative assumptions of thresholds for PM. Following advice from EPA's Science Advisory Board, both high and low threshold assumptions will be used to generate benefits estimates. The low threshold assumption will assume a threshold equal to anthropogenic background concentrations and the high threshold assumption will assume a threshold equal to the PM standard of 15 $\mu g/m^3$.

4.3 Ozone and PM Health-Related Benefits

While a broad range of adverse health effects have been associated with exposure to elevated ozone and PM levels, only subsets of health effects are selected for inclusion in the quantified benefit analysis. Effects are excluded from the current analysis (1) in order to prevent double counting (such as hospital admissions for specific respiratory diseases); (2) due to uncertainties in applying effect relationships based on clinical studies (where human subjects are exposed to various levels of air pollution in a carefully controlled and monitored laboratory situation) to the NOx SIP call affected population; or (3) due to a lack of an established concentration-response relationship.

The general format for the following sections detailing benefits for each endpoint is to begin with a discussion of the method and studies used for economic valuation, then present the studies used to obtain the concentration-response function for estimation of avoided incidences. Following these discussions, tables of avoided incidences and associated monetary benefits for ozone-related effects and PM-related effects are presented. Benefits estimates are presented for a subset of the regulatory alternatives presented in chapters 6, 7 and 9. Air quality changes used to generate the benefits estimates are not based on the final NOx SIP call control requirements. For additional information on air quality modeling scenarios for the benefits analysis, see Section 10.1.5. Numbers presented in the tables represent changes in the number of incidences and associated monetary benefits given the illustrative implementation of particular NOx control strategies relative to the 2007 baseline air quality. For endpoints which are affected by both ozone and PM, ozone-related benefits are presented first, followed by PM-related benefits.

A preliminary explanatory note on the calculation of the point estimates presented in the tables below is warranted. Each point estimate of monetary benefits in the tables below is the mean of a distribution of monetary benefits derived through a Monte Carlo procedure[2]. The estimate derived by this method approaches the simple product of the mean of the unit dollar distribution and the mean of the incidence change distribution, but for a finite number of iterations may be slightly off. For an illustrative example of the procedure and for further details, see Appendix A and the technical support document for this RIA (Abt Associates, 1998a).

For ozone, three health effects are selected for inclusion: mortality associated with short-term exposure, hospital admissions for all respiratory diseases, and acute respiratory symptoms. One other human health-related effect, decreased worker productivity, is included as a welfare effect rather than a health effect (see Section 4.3.4). The ozone-related effect categories that are included in the NOx SIP call analysis are shown in Table 4-5. Premature mortality is the only ozone-related endpoint for which a range of benefits is presented.

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[2] Each point estimate of avoided incidences presented in the tables below is the mean of a Latin Hypercube approximation of a distribution of avoided incidences reflecting the uncertainty in the pollutant coefficient in the C-R function. In the Latin Hypercube method 100 percentile points (in this case, the (n-0.5)th percentile points of the distribution, for n = 1, 2, ..., 100) are selected to represent the distribution. This reduces the computational burden associated with preserving the full distribution.

Table 4-5
Quantified Ozone-Related Health Effects Included in the Benefits Analysis

Health Effect	Affected Population	Study
Mortality		
Ozone-related short-term exposure mortality	all ages	pooled analysis of 4 U.S. studies
Hospital Admissions		
"All Respiratory"	all ages	Thurston et al., 1992
Respiratory Symptoms/Illnesses Not Requiring Hospitalization		
Acute respiratory symptoms (any of 19)	ages 18-65	Krupnick et al., 1990

Although the primary environmental purpose of the NOx SIP call is to help achieve attainment of the ozone NAAQS in the eastern United States, significant monetary benefits will also be associated with changes in ambient levels of PM. Several PM health endpoints are included in the quantified benefits estimation. The PM-related effect categories that are included in this analysis are shown in Table 4-6. For all of the PM-related endpoints, benefits are estimated using both the RADM-RPM and S-R Matrix generated PM concentrations. In addition, for health endpoints, benefits are estimated under both a background threshold assumption and an assumed threshold of 15 $\mu g/m^3$.

4.3.1 Premature Mortality

Both ozone and particulate matter have been associated with increased risk of premature mortality in adult populations. Avoided mortality is a very important health endpoint in this economic analysis due to the high monetary value associated with risks to life.

The benefits analysis uses the "statistical lives lost" approach to value avoided premature mortality. The mean value of avoiding one statistical death is estimated to be $4.8 million. This represents an intermediate value from a variety of estimates that appear in the economics literature, and is a value that EPA has frequently used in RIAs for other rules. This estimate is the mean of a fitted Weibull distribution of the estimates from 26 value-of-life studies identified in the §812 study as "applicable to policy analysis." The approach and set of selected studies mirrors that of Viscusi (1992) (with the addition of two studies), and uses the same criteria used by Viscusi in his review of value-of-life studies. The $4.8 million estimate is consistent with Viscusi's conclusion that "most of the reasonable estimates of the value of life are clustered in the $3 to $7 million range." Five of the 26 studies are contingent valuation (CV) studies, which directly solicit WTP information from subjects; the rest are wage-risk studies, which base WTP estimates on estimates of the additional compensation demanded in the labor market for riskier jobs. The 26 studies used to form the distribution of the value of a statistical life are listed in Table 4-7.

Table 4-6
Quantified PM-Related Health Effects Included in the Benefits Analysis

Endpoint	Population to Which Applied	Study
Mortality		
$PM_{2.5}$-related long-term exposure mortality	ages 30+	Pope et al., 1995
Hospital Admissions		
"all respiratory"	all ages	Thurston et al., 1994
Congestive heart failure	age 65+	Schwartz and Morris, 1995
Ischemic heart disease	age 65+	Schwartz and Morris, 1995
Chronic Bronchitis		
Development of chronic bronchitis	all	Schwartz, 1993
Respiratory Symptoms/Illnesses Not Requiring Hospitalization		
Acute bronchitis	ages 10-12	Dockery et al., 1989
$PM_{2.5}$-related lower respiratory symptoms (LRS)	ages 8-12	Schwartz et al., 1994
Upper respiratory symptoms (URS)	asthmatics, age 9-11	Pope et al., 1991
MRADs	ages 18-65	Ostro and Rothschild, 1989
Work loss days (WLDs)	ages 18-65	Ostro, 1987

There are two types of exposure to elevated levels of air polluation that may result in premature mortality. Acute (short-term) exposure (e.g., exposure on a given day) to peak pollutant concentrations may result in excess mortality on the same day or within a few days of the elevated exposure. Chronic (long-term) exposure (e.g., exposure over a period of a year or more) to levels of pollution that are generally higher may result in mortality in excess of what it would be if pollution levels were generally lower. The excess mortality that occurs will not necessarily be associated with any particular episode of elevated air pollution levels. Both types of effects are biologically plausible, and there is an increasing body of consistent corroborating evidence from animal toxicity studies indicating that both types of effects exist.

Table 4-7
Summary of Mortality Valuation Estimates[a]

Study	Type of Estimate	Valuation per Statistical Life (millions of 1990 $)
Kneisner and Leeth (1991) (U.S.)	Labor Market	0.6
Smith and Gilbert (1984)	Labor Market	0.7
Dillingham (1985)	Labor Market	0.9
Butler (1983)	Labor Market	1.1
Miller and Guria (1991)	Contingent Valuation	1.2
Moore and Viscusi (1988a)	Labor Market	2.5
Viscusi, Magat, and Huber (1991b)	Contingent Valuation	2.7
Gegax et al. (1985)	Contingent Valuation	3.3
Marin and Psacharopoulos (1982)	Labor Market	2.8
Kneisner and Leeth (1991) (Australia)	Labor Market	3.3
Gerking, de Haan, and Schulze (1988)	Contingent Valuation	3.4
Cousineau, Lacroix, and Girard (1988)	Labor Market	3.6
Jones-Lee (1989)	Contingent Valuation	3.8
Dillingham (1985)	Labor Market	3.9
Viscusi (1978, 1979)	Labor Market	4.1
R.S Smith (1976)	Labor Market	4.6
V.K. Smith (1976)	Labor Market	4.7
Olson (1981)	Labor Market	5.2
Viscusi (1981)	Labor Market	6.5
R.S. Smith (1974)	Labor Market	7.2
Moore and Viscusi (1988a)	Labor Market	7.3
Kneisner and Leeth (1991) (Japan)	Labor Market	7.6
Herzog and Schlottman (1987)	Labor Market	9.1
Leigh and Folson (1984)	Labor Market	9.7
Leigh (1987)	Labor Market	10.4
Gaten (1988)	Labor Market	13.5

[a] Source: Viscusi, 1992

There are, similarly, two basic types of epidemiological studies of the relationship between mortality and exposure to pollutants. Long-term studies (e.g., Pope et al., 1995) estimate the association between long-term (chronic) exposure to air pollution and the survival of members of a large study population over an extended period of time. Such studies examine the health endpoint of concern in relation to the general long-term level of the pollutant of concern -- for example, relating annual mortality to some measure of annual pollutant level. Daily peak concentrations would impact the results only insofar as they affect the measure of long-term (e.g., annual) pollutant concentration. In contrast, short-term studies relate daily levels of the pollutant to daily mortality. By their basic design, daily studies can detect acute effects but cannot detect the effects of long-term exposures. A chronic exposure study design (a prospective cohort study, such as the Pope study) is best able to identify the long-term exposure effects, and will likely detect some of the short-term exposure effects as well. Because a long-term exposure study may detect some of the same short-term exposure effects detected by short-term studies, including both types of study in a benefit analysis would likely result in some degree of double counting of benefits.

Another major advantage of the long-term study design concerns the issue of the degree of prematurity of mortality associated with air pollution. It is possible that the short-term studies are detecting an association between air pollution and mortality that is primarily occurring among terminally ill people. Critics of the use of short-term studies for policy analysis purposes correctly point out that an added risk factor that results in a terminally ill person dying a few days or weeks earlier than they otherwise would have (known as "short-term harvesting") is potentially included in the measured air pollutant mortality "signal" detected in such a study. As the short-term study design does not examine individual people (it examines daily mortality rates in large populations, typically a large city population), it is impossible to know anything about the overall health status of the specific population that is detected as dying early. While some of the detected excess deaths may have resulted in a substantial loss of life (measuring loss of life in terms of lost years of remaining life), others may have lost a relatively short amount of lifespan.

While the long-term study design is preferred, these types of studies are expensive to conduct and consequently there are relatively few well designed long-term studies. For PM, there has only been one high quality study accepted by the Science Advisory Board, and for ozone, no acceptable long-term studies have been published. For this reason, short-term ozone mortality is used as the basis for determining ozone-related mortality benefits for the NOx SIP call.

The next two sections provide details on the measurement and valuation of changes in incidences of premature mortality associated with changes in ozone and PM arising from implementation of the NOx SIP call.

Ozone-related Mortality

The literature on the possible relationship between exposure to ambient ozone and premature mortality has been evolving rapidly. Of the 28 time-series epidemiology studies identified in the literature that report results on a possible association between daily ozone concentrations and daily mortality (see EPA, 1997a, Appendix J), 21 were published or presented since 1995. In particular, a series of studies published in 1995 through 1997 (after closure on the ozone Criteria Document) from multiple cities in western Europe has significantly increased the body of studies finding a positive association. Fifteen of the 28 studies report a statistically significant relationship between ozone and mortality, with the more recent studies tending to find statistical significance more often than the earlier studies. The ozone-mortality datasets have also tended to become larger in more recent studies as longer series of air quality monitoring data have become available over time. This suggests that it may take many years of data before the ozone effect can be separated from the daily weather and seasonal patterns with which it tends to be correlated.

In 1997, as a part of the ozone NAAQS promulgation RIA, EPA staff reviewed this recent literature. They identified 9 studies that met a defined set of selection criteria, and conducted a meta-analysis of the results of the 9 studies. The result of this work was included as Appendix J in the NAAQS RIA, "Assessment and Synthesis of Available Epidemiological Evidence of Mortality Associated with Ambient Ozone from Daily Time-series Analyses" (EPA, 1997a).

The NOx SIP call related benefits analysis implements the same basic meta-analysis approach to quantifying ozone mortality as the NAAQS RIA, with the exception that a subset of 4 of the 9 studies is used, representing only U.S. based analyses. In a post-NAAQS RIA review of the methodology for assessing ozone mortality effects, it was determined that the relationships between ambient ozone and mortality in the non-U.S. study locations included in the original NAAQS-related meta-analysis may not be representative of the range of ozone-mortality concentration-response relationships in the United States. Although ozone is the same everywhere (in contrast to PM), its effects on mortality may depend on its interactions with other pollutants and with meteorological variables. In addition, there are population and societal differences (air conditioning incidence, building construction, human activity patterns, etc.) across locations that could affect the relationship between ambient ozone levels and mortality. To reduce the potential for applying inappropriate concentration-response functions in analysis of the ozone mortality benefits from the NOx SIP call, only U.S. studies are included, based on the assumption that demographic and environmental conditions on average would be more similar between the study and policy sites. However, the full body of peer-reviewed ozone mortality studies should be considered when evaluating the weight of evidence regarding the presence of an association between ambient ozone concentrations and premature mortality.

Because of differences in the averaging times used in the underlying studies (some use daily average ozone levels, while others use 1-hour daily maximum values), it is not possible to conduct a meaningful meta-analysis directly on the coefficients of the C-R functions. Instead, for each pair of air quality modeling results (for the baseline and a given regulatory alternative) for the NOx SIP call, each C-R function is translated into a set of predicted mortality incidence changes that would be estimated by that C-R function, given the set of air quality changes. The meta-analysis approach is then applied to the predicted mortality incidence changes that would be estimated by each of the studies. Additional details of the approach are described in the technical support document for the NOx SIP call (Abt Associates, 1998a).

Table 4-8 presents the range of estimates of avoided incidences of ozone-related mortality and monetary benefits associated with five regulatory alternatives for the NOx SIP call. Note that the lower estimate for this endpoint is zero to reflect both the number of peer-reviewed studies finding no significant relationship between ozone and premature mortality and the lack of a directly established biological mechanism linking ozone and premature mortality. In its review of the epidemiological ozone-mortality literature, EPA has determined that there is a reasonable probability that increased ozone concentrations are associated with incidences of premature mortality. In Table 4-8 the higher estimate allows for the existence of an ozone-mortality relationship, but assumes there is some probability that for any specific location within the SIP call region that the effect of ozone on premature mortality is zero. This probability is embedded in the previously discussed meta-analysis approach, which includes studies both with and without findings of a statistically significant relationship between ozone concentrations and premature mortality.

Note that the high estimate presented in Table 4-8 does not represent the limiting upper end of potential ozone-related mortality benefits. The high estimate in Table 4-8 represents the mean estimate of benefits derived from the distribution of concentration-response functions generated from the meta-analysis described above. The limiting upper end for ozone-related mortality is generated by assuming that the highest concentration-response function applies everywhere. This would generate a benefits estimate considerably higher than the high estimate in Table 4-8.

Table 4-8
Range of Avoided Ozone-related Mortality Incidences and Monetary Benefits Associated with the NOx SIP Call[a]

Regulatory Alternative	Avoided Incidences (cases/year)		Monetary Benefits (millions 1990$)	
	Low	High	Low	High
0.12 Trading	0	315	$0	$1,496
0.15 Trading	0	279	$0	$1,326
Regionality I	0	251	$0	$1,191
0.20 Trading	0	234	$0	$1,108
0.25 Trading	0	174	$0	$824

[a] Annual baseline incidence for non-accidental deaths in the general population for all ages is 803/100,000. Total annual baseline incidence for the NOx SIP call region is 1,768,014 non-accidental deaths.

PM-related Mortality

PM-associated mortality in the benefits analysis is estimated using the $PM_{2.5}$ relationship from Pope et al., 1995. This decision reflects the Science Advisory Board's explicit recommendation for modeling the mortality effects of PM in both the completed §812 Retrospective Report to Congress and the ongoing §812 Prospective Study. The Pope study estimates the association between long-term (chronic) exposure to $PM_{2.5}$ and the survival of members of a large study population. This relationship is selected for use in the benefits analysis instead of short-term (daily pollution) studies for a number of reasons.

The Pope long-term study is selected as providing the best available estimate of the relationship between PM and mortality. It is used alone, rather than considering the total effect to be the sum of estimated short-term and long-term effects, because summing creates the possibility of double-counting a portion of total mortality. The Pope study is selected in preference to other available long-term studies because it uses the best methods (i.e., a prospective cohort method with a Cox proportional hazard model), and has a much larger cohort population, the longest exposure interval, and more locations (51 cities) in the United States, than other studies. It is unlikely that the Pope study contains any significant amount of short-term harvesting. First, the health status of each individual tracked in the study is known at the beginning of the study period. Persons with known pre-existing serious illnesses were excluded from the study population. Second, the Cox proportional hazard statistical model used in the Pope study examines the question of survivability throughout the study period (10 years). Deaths that are premature by only a few days or weeks within the 10-year study period (for example, the deaths of terminally ill patients, triggered by a short duration PM episode) are likely to have little impact on the calculation of the average probability of surviving the entire 10 year interval. In relation to the other prospective cohort study (Dockery, et al., 1992, the "Six-cities" cohort study), the Pope study found a smaller increase in excess mortality for a given PM air quality change.

Table 4-9 presents point estimates of avoided incidences of long-term PM-related mortality and monetary benefits associated with the five regulatory alternatives for the NOx SIP call. As noted earlier, non-linearities inherent in the RADM-RPM air quality model lead to an inconsistent ranking of results between the RADM-RPM and S-R Matrix results. With the exception of the 0.12 trading alternative, estimated premature mortality incidences are higher for S-R Matrix generated PM changes than for RADM-RPM generated PM changes.

Table 4-9
Avoided Long Term PM-related Mortality Incidences and Monetary Benefits Associated with the NOx SIP call[a]

Regulatory Alternative	Avoided Incidences (cases/year)				Monetary Benefits (millions 1990$)			
	RADM-RPM		S-R Matrix		RADM-RPM		S-R Matrix	
	15 $\mu g/m^3$	Back ground	15 $\mu g/m^3$	Back ground	15 $\mu g/m^3$	Back ground	15 $\mu g/m^3$	Back ground
0.12 Trading	310	657	306	561	$1,468	$3,173	$1,459	$2,672
0.15 Trading	53	101	231	370	$251	$482	$1,099	$1,763
Regionality 1	67	94	190	278	$317	$459	$904	$1,326
0.20 Trading	78	149	216	315	$370	$715	$1,028	$1,499
0.25 Trading	44	75	202	294	$208	$358	$962	$1,400

[a] Annual baseline incidence for non-accidental deaths in the general population aged over 30 is 759/100,000. Total annual baseline incidence for the NOx SIP call region is 929,557 non-accidental deaths.

The estimates of excess mortality from the short-term studies are presented as an important sensitivity analysis. Because there is only one short-term study (presenting results from 6 separate U.S.

cities) that uses $PM_{2.5}$ as the metric of PM (Schwartz et al., 1996), an estimate based on the pooled city-specific, short-term $PM_{2.5}$ results will be presented.

Table 4-10 presents the results of a sensitivity analysis using mortality associated with short-term exposure to $PM_{2.5}$. In some cases, the avoided incidences of mortality (and corresponding monetary benefits) predicted using the short-term function are higher than those predicted using the long-term function, and in other cases the reverse is true. For the RADM-RPM background threshold results, the magnitude of the difference between the value of avoided incidences of short- and long-term mortality ranges from $-1,539 million for the 0.12 trading alternative to $207 million for the Regionality 1 alternative. For the S-R Matrix background threshold results, the magnitude of the difference ranges from $-1,703 million for the 0.12 trading alternative to $-709 million for the Regionality 1 alternative. As with long-term mortality, the relationship between the RADM-RPM and S-R Matrix generated results is not consistent across alternatives, due to the differences in air chemistry modeling between the two models. In addition, the rank ordering across threshold levels is not consistent across alternatives.

Table 4-10
Sensitivity Analysis: Premature Mortality Benefits
Using Avoided Short Term PM-related Mortality Incidences[a]

Regulatory Alternative	Avoided Incidences (cases/year)				Monetary Benefits (millions 1990$)			
	RADM-RPM		S-R Matrix		RADM-RPM		S-R Matrix	
	15 μg/m³	Back ground	15 μg/m³	Back ground	15 μg/m³	Back ground	15 μg/m³	Back ground
0.12 Trading	293	339	136	203	$1,393	$1,634	$649	$969
0.15 Trading	130	128	110	152	$619	$615	$523	$726
Regionality 1	129	136	99	129	$614	$666	$473	$617
0.20 Trading	113	129	103	138	$536	$619	$493	$658
0.25 Trading	76	91	99	132	$360	$434	$473	$630

[a] Annual baseline incidence for non-accidental deaths in the general population is 803/100,000. Total annual baseline incidence for the NOx SIP call region is 1,768,014 non-accidental deaths for the population aged over 30.

A new study (Woodruff et al, 1997) finds a significant association between annual PM_{10} levels and post-neonatal (infants aged 28 - 51 weeks) mortality. Conceptually any additional mortality from this function would be additive to the Pope results (because the Pope function covers only the population over 30 years old), although not additive to the daily mortality studies (which cover all ages). The SAB recently advised the §812 Prospective project to not include this in the §812 primary analysis at this time, primarily because the study is of a new endpoint and the results have not been replicated in other studies in the U.S. The coherence and consistency arguments which support the use of the Pope study are not present with this study at this time. For the SIP call analysis, this endpoint is presented as a sensitivity analysis. $PM_{2.5}$ changes associated with the NOx SIP call are used with this PM_{10} C-R function. This will produce a conservative estimate of infant mortality for two reasons. First, there may be some reductions in the coarse fraction (PM between 2.5 and 10 microns in diameter) that result from the NOx reductions which will be omitted from the analysis. Perhaps more importantly, estimating infant mortality using the estimated change in $PM_{2.5}$ levels in a PM_{10} function implicitly assumes that the fine fraction of PM is no more toxic than the coarse fraction. EPA's decision in 1997 to set an additional NAAQS using $PM_{2.5}$ in addition to a PM_{10} standard, is based in part on a growing scientific consensus that the fine fraction of the total PM_{10} mass is likely to be most associated with adverse health effects. If in fact the toxicity of $PM_{2.5}$ is greater than the toxicity of PM_{10}, then using changes in $PM_{2.5}$ in a C-R function based on PM_{10} will underestimate the total effect on infant mortality.

Table 4-11 presents a sensitivity analysis using neo-natal mortality. Monetary benefits associated with the avoided incidences are not presented due to a lack of information about the value of avoided neo-natal mortality. It is likely that avoided infant mortalities will be valued higher than mortalities for adults. However, at present, no studies have been conducted to determine this value. For this reason, only avoided incidences of neo-natal mortality are presented in Table 4-11.

Table 4-11
Sensitivity Analysis: Avoided Post Neo-natal PM-related Mortality Incidences

Regulatory Alternative	Avoided Incidences (cases/year)			
	RADM-RPM		S-R Matrix	
	15 $\mu g/m^3$	Back ground	15 $\mu g/m^3$	Back ground
0.12 Trading	5	5	2	2
0.15 Trading	2	2	2	2
Regionality 1	2	2	1	1
0.20 Trading	2	2	1	1
0.25 Trading	1	1	1	1

4.3.2 Hospital Admissions

An individual's WTP to avoid a hospital admission will include, at a minimum, the amount of money they pay for medical expenses (i.e., what they pay towards the hospital charge and the associated physician charge) and the loss in earnings. In addition, however, an individual is likely to be willing to pay some amount to avoid the pain and suffering associated with the illness itself. That is, even if they incurred no medical expenses and no loss in earnings, most individuals would still be willing to pay something to avoid the illness.

Because medical expenditures are to a significant extent shared by society, via medical insurance, Medicare, etc., the medical expenditures actually incurred by the individual are likely to be less than the total medical cost to society. The total value to society of an individual's avoidance of hospital admission, then, might be thought of as having two components: (1) the cost of illness (COI) to society, including the total medical costs plus the value of the lost productivity, as well as (2) the individual's WTP to avoid the disutility of the illness itself (e.g., the pain and suffering associated with the illness).

In the absence of estimates of social WTP to avoid hospital admissions for specific illnesses (components 1 plus 2 above), estimates of total COI (component 1) are typically used as conservative (lower bound) estimates. Because these estimates do not include the value of avoiding the disutility of the illness itself (component 2), they are biased downward. Some analyses adjust COI estimates upward by multiplying by an estimate of the ratio of WTP to COI, to better approximate total WTP. Other analyses have avoided making this adjustment because of the possibility of over adjusting -- that is, possibly replacing a known downward bias with an upward bias. The previous RIAs for PM and ozone, as well as the revised RIA for ozone and PM NAAQS, did adjust the COI estimate upward. The COI values used in the benefits analysis for the SIP call benefits will not be adjusted to better reflect the total WTP. This is consistent with the guidance offered by the §812 SAB committee.

The COI estimates used in this RIA include the estimated hospital and physician charges, based on the average length of a hospital stay for the illness, and the estimated opportunity cost of time spent in the hospital.

Ozone-related Hospital Admissions

The benefits analysis includes a single ozone-related effect category for hospital admissions: all respiratory diseases. The study that estimated the C-R function (Thurston et al., 1992) examined hospital admissions for all ages in the population. Because of the comprehensiveness of the Thurston study, it is selected over other available studies that are restricted to limited age ranges (e.g., the population aged 65 year and older), and/or specific diagnoses (e.g., hospital admissions for pneumonia). The age- and disease-specific effect categories are subsets of the all-age, all-respiratory disease hospital admission category. Therefore, the benefits of avoided hospital admissions for respiratory illnesses for all ages should be larger than the benefits for more restricted categories. However, that is not true for the estimated benefits, based on the available studies. The Thurston estimated relationship produces fewer benefits than either of the two available alternatives: all respiratory disease admissions for the population over 65; or the sum of pneumonia and chronic obstructive pulmonary disease (COPD) admissions for the population over 65. Clearly adding the results for these study types would involve a serious amount of double counting. Therefore, selecting the Thurston study may underestimate the total benefits of hospital admissions.

Table 4-12 presents point estimates of avoided incidences of hospital admissions for all ozone-related respiratory symptoms and monetary benefits associated with the five regulatory alternatives for the NOx SIP call.

Table 4-12
Avoided Ozone-related Hospital Admissions and Monetary Benefits
Associated with the NOx SIP Call[a]

Regulatory Alternative	Avoided Incidences (cases/year)	Monetary Benefits (millions 1990$)
0.12 Trading	719	$5
0.15 Trading	637	$4
Regionality 1	571	$4
0.20 Trading	533	$4
0.25 Trading	396	$3

[a] Annual baseline incidence for all respiratory-related hospital admissions (not just ozone related) in the general population is 504/100,000. Total annual baseline incidence for the NOx SIP call region is 1,109,687 admissions.

PM-related Hospital Admissions

The benefits analysis includes three PM-related hospital admissions, due to all respiratory illnesses, congestive heart failure, and ischemic heart disease. As with ozone-induced hospital admissions, the benefits analysis relies on a study of all respiratory hospital admissions for all age groups, rather than studies examining the population over 65. Table 4-13 presents point estimates of avoided incidences of PM-related hospital admissions and monetary benefits associated with the five regulatory alternatives for the NOx SIP call.

Table 4-13
Avoided PM-related Hospital Admissions and Monetary Benefits Associated with the NOx SIP Call[a]

Regulatory Alternative		Avoided Incidences (cases/year)				Monetary Benefits (millions 1990$)			
		RADM-RPM		S-R Matrix		RADM-RPM		S-R Matrix	
		15 $\mu g/m^3$	Back ground	15 $\mu g/m^3$	Back ground	15 $\mu g/m^3$	Back ground	15 $\mu g/m^3$	Back ground
0.12 Trading	AR[b]	305	354	518	589	$1.9	$2.2	$3.3	$3.7
	CHF	61	63	26	28	$0.5	$0.5	$0.2	$0.2
	IHD	67	70	29	31	$0.7	$0.7	$0.3	$0.3
0.15 Trading	AR	135	133	491	535	$0.9	$0.8	$3.1	$3.4
	CHF	23	24	17	18	$0.2	$0.2	$0.1	$0.1
	IHD	25	27	19	20	$0.3	$0.3	$0.2	$0.2
Regionality 1	AR	133	139	479	511	$0.8	$0.9	$3.0	$3.2
	CHF	24	26	13	14	$0.2	$0.2	$0.1	$0.1
	IHD	27	28	14	15	$0.3	$0.3	$0.1	$0.2
0.20 Trading	AR	117	133	484	520	$0.7	$0.8	$3.1	$3.3
	CHF	22	24	14	15	$0.2	$0.2	$0.1	$0.1
	IHD	24	27	16	17	$0.2	$0.3	$0.2	$0.2
0.25 Trading	AR	78	94	480	515	$0.5	$0.6	$3.0	$3.3
	CHF	14	17	13	14	$0.1	$0.1	$0.1	$0.1
	IHD	15	19	15	16	$0.2	$0.2	$0.2	$0.2

[a] Annual baseline incidence in the general population is 504/100,000 for all respiratory, 231/100,000 for congestive heart failure, and 450/100,000 for ischemic heart disease. Total annual baseline incidence for the NOx SIP call region is 1,109,687 admissions for all respiratory, 508,607 admissions for congestive heart failure, and 990,792 admissions for ischemic heart disease.

[b] AR refers to all respiratory, CHF refers to congestive heart failure, and IHD refers to ischemic heart disease.

4.3.3 Bronchitis

Chronic bronchitis is the only measured morbidity endpoint that may be expected to last from the initial onset of the illness throughout the rest of the individual's life. WTP to avoid chronic bronchitis would therefore be expected to incorporate the present discounted value of a potentially long stream of costs (e.g., medical expenditures and lost earnings) and pain and suffering associated with the illness. Two studies, Viscusi et al. (1991) and Krupnick and Cropper (1992) provide estimates of WTP to avoid a case of chronic bronchitis. The study by Viscusi et al., however, uses a sample that is larger and more representative of the general population than the study by Krupnick and Cropper (which selects people who have a relative with the disease). The valuation of chronic bronchitis in this analysis is therefore based on the distribution of WTP responses from Viscusi et al. (1991).

Both Viscusi et al. (1991) and Krupnick and Cropper (1992), however, defined a case of severe chronic bronchitis. It is unclear what proportion of the cases of chronic bronchitis predicted to be associated with exposure to pollution would turn out to be severe cases. The estimated incidence of pollution-related chronic bronchitis related to the SIP call emission reductions is based on two studies (Abbey et al., 1993 and Schwartz, 1993), which consider only new cases of the illness. While a new case may not start out being severe, chronic bronchitis is an illness that may progress in severity from onset throughout the rest of the individual's life. It is the chronic illness that is being valued, rather than the illness at onset.

The WTP to avoid a case of pollution-related chronic bronchitis (CB) is derived by starting with the WTP to avoid a severe case of chronic bronchitis, as described by Viscusi et al. (1991), and adjusting it downward to reflect (1) the decrease in severity of a case of pollution-related CB relative to the severe case described in the Viscusi study, and (2) the elasticity of WTP with respect to severity reported in the Krupnick and Cropper study. The adjustment procedure is described in more detail in the technical support document (Abt Associates, 1998a). The mean value of the adjusted distribution is $260,000.

Estimating WTP to avoid a case of acute bronchitis is difficult for several reasons. First, WTP to avoid acute bronchitis itself has not been estimated. Estimation of WTP to avoid this health endpoint therefore must be based on estimates of WTP to avoid symptoms that occur with this illness. Second, a case of acute bronchitis may last more than one day, whereas it is a day of avoided symptoms that is typically valued. Finally, the concentration-response function used in the benefit analysis for acute bronchitis was estimated for children, whereas WTP estimates for those symptoms associated with acute bronchitis were obtained from adults.

With these caveats in mind, a rough estimate of WTP to avoid a case of acute bronchitis was derived as the midpoint of a low and a high estimate. The low estimate ($13.29) is the sum of the midrange values recommended by IEc (IEc, 1994) for two symptoms believed to be associated with acute bronchitis: coughing ($6.29) and chest tightness ($7.00). The high estimate was taken to be twice the value of a minor respiratory restricted activity day ($38.37), or $76.74. The midpoint between the low and high estimates is $45.00. This value was used as the point estimate of MWTP to avoid a case of acute bronchitis in the benefit analysis.

Table 4-14 presents point estimates of avoided incidences of PM-related chronic and acute bronchitis and monetary benefits associated with the five regulatory alternatives for the NOx SIP call.

Table 4-14
Avoided Incidences of PM-related Chronic and Acute Bronchitis and Monetary Benefits Associated with the NOx SIP Call

Regulatory Alternative	Avoided Incidences (cases/year)				Monetary Benefits (millions 1990$)			
	RADM-RPM		S-R Matrix		RADM-RPM		S-R Matrix	
	15 $\mu g/m^3$	Back ground	15 $\mu g/m^3$	Back ground	15 $\mu g/m^3$	Back ground	15 $\mu g/m^3$	Back ground
0.12 Trading								
Chronic	2,060	2,054	891	909	$589	$574	$240	$245
Acute	1,148	2,171	424	917	$0.1	$0.1	$0.0	$0.0
0.15 Trading								
Chronic	787	782	587	595	$225	$213	$158	$160
Acute	535	827	313	609	$0.0	$0.0	$0.0	$0.0
Regionality 1								
Chronic	825	823	449	455	$236	$223	$121	$122
Acute	517	859	257	453	$0.0	$0.0	$0.0	$0.0
0.20 Trading								
Chronic	785	784	499	500	$216	$221	$134	$135
Acute	472	809	294	519	$0.0	$0.0	$0.0	$0.0
0.25 Trading								
Chronic	550	548	469	471	$148	$150	$126	$127
Acute	352	574	276	490	$0.0	$0.0	$0.0	$0.0

4.3.4 Acute Respiratory Symptoms

There are three sources of uncertainty in the valuation of upper or lower respiratory symptoms: (1) an occurrence of URS or of LRS may be comprised of one or more of a variety of symptoms (i.e., URS and LRS are each potentially a "complex of symptoms"), so that what is being valued may vary from one occurrence to another; (2) for a given symptom, there is uncertainty about the mean WTP to avoid the symptom; and (3) the WTP to avoid an occurrence of multiple symptoms may be greater or less than the sum of the WTPs to avoid the individual symptoms.

Ozone-Related Respiratory Symptoms

"Presence of any of 19 acute respiratory symptoms" is a somewhat subjective "health endpoint" used by Krupnick et al. (1990). Moreover, not all 19 symptoms are listed in the Krupnick study. It is therefore not clear exactly what symptoms were included in the study. Even if all 19 symptoms were known, it is unlikely that WTP estimates could be obtained for all of the symptoms. Finally, even if all 19 symptoms were known and WTP estimates could be obtained for all 19 symptoms, the assumption of additivity of WTPs becomes tenuous with such a large number of symptoms. The likelihood that all 19 symptoms would occur simultaneously, moreover, is very small.

Acute respiratory symptoms must be either upper respiratory symptoms or lower respiratory symptoms. In the absence of further knowledge about which of the two types of symptoms is more likely to occur among the "any of 19 acute respiratory symptoms," it was assumed that they occur with equal probability. Because this health endpoint may also consist of combinations of symptoms, it was also assumed that there is some (smaller) probability that upper and lower respiratory symptoms occur together.

To value avoidance of a day of "the presence of any of 19 acute respiratory symptoms" it was therefore assumed that this health endpoint consists either of URS, or LRS, or both. It was also assumed that it is as likely to be URS as LRS and that it is half as likely to be both together. That is, it was assumed that "the presence of any of 19 acute respiratory symptoms" is a day of URS with 40% probability, a day of LRS with 40% probability, and a day of both URS and LRS with 20% probability. Using the point estimates of WTP to avoid a day of URS and LRS derived above, the point estimate of WTP to avoid a day of "the presence of any of 19 acute respiratory symptoms" is

$$(0.40)(\$18.70) + (0.40)(\$11.82) + (0.20)(\$18.70 + \$11.82) = \$18.31 \quad . \tag{1}$$

Because this health endpoint is only vaguely defined, and because of the lack in information on the relative frequencies of the different combinations of acute respiratory symptoms that might qualify as "any of 19 acute respiratory symptoms," the unit dollar value derived for this health endpoint must be considered only a rough approximation.

Table 4-15 presents point estimates of avoided incidences of ozone-related respiratory symptoms and monetary benefits associated with the five regulatory alternatives for the NOx SIP call.

Table 4-15
Avoided Incidences of Ozone-related Respiratory Symptoms and Monetary Benefits Associated with the NOx SIP Call

Regulatory Alternative	Avoided Incidences (cases/year)	Monetary Benefits (millions 1990$)
0.12 Trading	68,919	$1.3
0.15 Trading	61,015	$1.2
Regionality 1	54,757	$1.0
0.20 Trading	51,053	$1.0
0.25 Trading	37,908	$0.7

PM Related Upper Respiratory Symptoms

The concentration-response function for URS is taken from Pope et al. (1991). Pope et al. describe URS as consisting of one or more of the following symptoms: runny or stuffy nose; wet cough; and burning, aching, or red eyes. The children in the Pope study were asked to record respiratory symptoms in a daily diary, and the daily occurrences of URS and LRS, as defined above, were related to daily PM-10 concentrations. Estimates of WTP to avoid a day of symptoms are therefore appropriate measures of benefit.

Willingness to pay to avoid a day of URS is based on symptom-specific WTPs to avoid those symptoms identified by Pope et al. as part of the URS complex of symptoms. Three contingent valuation (CV) studies have estimated WTP to avoid various morbidity symptoms that are either within the URS symptom complex defined by Pope et al. or are similar to those symptoms identified by Pope et al. In each CV study, participants were asked their WTP to avoid a day of each of several symptoms. The three individual symptoms that were identified as most closely matching those listed by Pope et al. for URS are cough, head/sinus congestion, and eye irritation. A day of URS could consist of any one of seven possible "symptom complexes" consisting of at least one of these symptoms. It is assumed that each of the seven types of URS is equally likely. The *ex ante* MWTP to avoid a day of URS is therefore the average of the MWTPs to avoid each type of URS, or $18.70. This is the point estimate for the dollar value for URS used in the benefit analysis. Finally, it is worth emphasizing that what is being valued here is URS *as defined by Pope et al., 1991.* While other definitions of URS are certainly possible, this definition of URS is used in this benefit analysis because it is the incidence of this specific definition of URS that has been related to PM exposure by Pope et al., 1991.

PM Related Lower Respiratory Symptoms

Schwartz et al. (1994) estimated the relationship between LRS and PM-10 concentrations. The method for deriving a point estimate of MWTP to avoid a day of LRS is the same as for URS. Schwartz et al. (1994) define LRS as at least two of the following symptoms: cough, chest pain, phlegm, and wheeze. The symptoms for which WTP estimates are available that reasonably match those listed by Schwartz et al. for LRS are cough (C), chest tightness (CT), coughing up phlegm (CP), and wheeze (W). A day of LRS, as defined by Schwartz et al., could consist of any one of the 11 combinations of at least two of these four symptoms.

It is assumed that each of the eleven types of LRS is equally likely. The *ex ante* MWTP to avoid a day of LRS as defined by Schwartz is therefore the average of the MWTPs to avoid each type of LRS, or $11.82. This is the point estimate used in the benefit analysis for the dollar value for LRS as defined by Schwartz et al. The WTP estimates are based on studies which considered the value of a *day* of avoided symptoms, whereas the Schwartz study used as its measure a *case* of LRS. Because a case of LRS usually lasts at least one day, and often more, WTP to avoid a day of LRS should be a conservative estimate of WTP to avoid a case of LRS.

Finally, as with URS, it is worth emphasizing that what is being valued here is LRS *as defined by Schwartz et al., 1994.* While other definitions of LRS are certainly possible, this definition of LRS is used in this benefit analysis because it is the incidence of this specific definition of LRS that has been related to PM exposure by Schwartz et al., 1994.

The point estimates derived for MWTP to avoid a day of URS and a case of LRS are based on the assumption that WTPs are additive. For example, if WTP to avoid a day of cough is \$7.00, and WTP to avoid a day of shortness of breath is \$5.00, then WTP to avoid a day of both cough and shortness of breath is \$12.00. If there are no synergistic effects among symptoms, then it is likely that the marginal utility of avoiding symptoms decreases with the number of symptoms being avoided. If this is the case, adding WTPs would tend to overestimate WTP for avoidance of multiple symptoms. However, there may be synergistic effects -- that is, the discomfort from two or more simultaneous symptoms may exceed the sum of the discomforts associated with each of the individual symptoms. If this is the case, adding WTPs would tend to underestimate WTP for avoidance of multiple symptoms. It is also possible that people may experience additional symptoms for which WTPs are not available, again leading to an underestimate of the correct WTP. However, for small numbers of symptoms, the assumption of additivity of WTPs is unlikely to result in substantive bias.

Table 4-16 presents point estimates of avoided incidences of PM-related upper and lower respiratory symptoms and monetary benefits associated with the five regulatory alternatives for the NOx SIP call. Note that the magnitude of incidences and the magnitude of monetary benefits are very different. This is due to the small value per avoided incidence for upper and lower respiratory symptoms.

4.3.5 Worker Productivity

The valuation used to monetize benefits associated with increased worker productivity resulting from improved ozone air quality is based on information reported in Crocker and Horst, 1981 and summarized in EPA, 1994. Crocker and Horst (1981) examined the impacts of ozone exposure on the productivity of outdoor citrus workers. Productivity impacts were measured as the change in income associated with a change in ozone exposure, given as the elasticity of income with respect to ozone concentration (-0.1427). The reported elasticity, which is used as the central estimate in this analysis, translates a 10 percent reduction in ozone to a 1.4 percent increase in income. Given the average daily income for outdoor workers engaged in strenuous activity reported by the 1990 U.S. census, \$73 per day, the 10 percent reduction in ozone yields approximately \$1 in increased daily wages.

Table 4-17 presents estimates of monetary benefits arising from ozone-related avoided lost worker productivity associated with the five regulatory alternatives for the NOx SIP call.

Table 4-16
Avoided Incidences of PM-related Upper and Lower Respiratory Symptoms and Monetary Benefits Associated with the NOx SIP Call[a]

Regulatory Alternative	Avoided Incidences (cases/year)				Monetary Benefits (millions 1990$)			
	RADM-RPM		S-R Matrix		RADM-RPM		S-R Matrix	
	15 $\mu g/m^3$	Back ground	15 $\mu g/m^3$	Back ground	15 $\mu g/m^3$	Back ground	15 $\mu g/m^3$	Back ground
0.12 Trading								
URS[b]	1,639	1,683	682	748	$0.0	$0.0	$0.0	$0.0
LRS	16,051	18,675	4,604	8,328	$0.2	$0.2	$0.1	$0.1
0.15 Trading								
URS	623	655	459	494	$0.0	$0.0	$0.0	$0.0
LRS	7,162	7,151	3,208	5,572	$0.1	$0.1	$0.0	$0.1
Regionality 1								
URS	642	667	343	368	$0.0	$0.0	$0.0	$0.0
LRS	6,853	7,313	2,567	4,189	$0.1	$0.1	$0.0	$0.0
0.20 Trading								
URS	585	650	389	414	$0.0	$0.0	$0.0	$0.0
LRS	6,190	7,057	2,858	4,771	$0.1	$0.1	$0.0	$0.1
0.25 Trading								
URS	392	462	372	396	$0.0	$0.0	$0.0	$0.0
LRS	4,107	4,934	2,677	4,521	$0.0	$0.1	$0.0	$0.1

[a] Annual baseline incidence in the applied population (asthmatics, ages 9-11) is 38,187 for upper respiratory symptoms. Information on baseline incidence is not available for lower respiratory symptoms.

[b] URS=upper respiratory symptom, LRS=lower respiratory symptom.

Table 4-17
Monetary Benefits from Ozone-related Avoided Lost Worker Productivity Associated with the NOx SIP Call

Regulatory Alternative	Monetary Benefits (millions 1990$)
0.12 Trading	$25
0.15 Trading	$22
Regionality 1	$20
0.20 Trading	$19
0.25 Trading	$14

4.3.6 Work loss days

Willingness to pay to avoid the loss of one day of work was estimated by dividing the median weekly wage for 1990 (U.S. Department of Commerce, 1992) by 5 (to get the median daily wage). This values the loss of a day of work at the median wage for the day lost. Valuing the loss of a day's work at the wages lost is consistent with economic theory, which assumes that an individual is paid exactly the value of his labor.

The use of the median rather than the mean, however, requires some comment. If all individuals in society were equally likely to be affected by air pollution to the extent that they lose a day of work because of it, then the appropriate measure of the value of a work loss day would be the mean daily wage. It is highly likely, however, that the loss of work days due to pollution exposure does not occur with equal probability among all individuals, but instead is more likely to occur among lower income individuals than among high income individuals. It is probable, for example, that individuals who are vulnerable enough to the negative effects of air pollution to lose a day of work as a result of exposure tend to be those with generally poorer health care. Individuals with poorer health care have, on average, lower incomes. To estimate the average lost wages of individuals who lose a day of work because of exposure to PM pollution, then, would require a weighted average of all daily wages, with higher weights on the low end of the wage scale and lower weights on the high end of the wage scale. Because the appropriate weights are not known, however, the median wage was used rather than the mean wage. The median is more likely to approximate the correct value than the mean because means are highly susceptible to the influence of large values in the tail of a distribution (in this case, the small percentage of very large incomes in the United States), whereas the median is not susceptible to these large values. The median daily wage in 1990 was $83.00.

Table 4-18 presents point estimates of avoided PM-related work loss days and monetary benefits associated with the five regulatory alternatives for the NOx SIP call.

Table 4-18
Avoided PM-related Work Loss Days and Monetary Benefits Associated with the NOx SIP Call[a]

Regulatory Alternative	Avoided Incidences (cases/year)				Monetary Benefits (millions 1990$)			
	RADM-RPM		S-R Matrix		RADM-RPM		S-R Matrix	
	15 μg/m^3	Back ground	15 μg/m^3	Back ground	15 μg/m^3	Back ground	15 μg/m^3	Back ground
0.12 Trading	167,124	194,481	53,315	91,557	$14	$16	$4	$8
0.15 Trading	74,345	73,325	38,262	62,300	$6	$6	$3	$5
Regionality 1	73,703	77,953	32,149	49,258	$6	$6	$3	$4
0.20 Trading	64,608	74,176	34,696	54,163	$5	$6	$3	$4
0.25 Trading	43,136	52,333	32,391	50,801	$4	$4	$3	$4

[a] Annual baseline incidence is 150,750 days/year per 100,000 workers between the ages of 18 and 65.

4.3.7 Minor restricted activity days

No studies are reported to have estimated WTP to avoid a minor restricted activity day (MRAD). However, IEc (1993) has derived an estimate of WTP to avoid a minor respiratory restricted activity day (MRRAD), using WTP estimates from Tolley et al. (1986) for avoiding a three symptom combination of coughing, throat congestion, and sinusitis. This estimate of WTP to avoid a MRRAD, so defined, is $38.37. Although Ostro and Rothschild (1989) estimated the relationship between PM-2.5 and MRADs, rather than MRRADs (a component of MRADs), it is likely that most of the MRADs associated with exposure to PM-2.5 are in fact MRRADs. For the purpose of valuing this health endpoint, then, it is assumed that MRADs associated with PM exposure may be more specifically defined as MRRADs, and the estimate of MWTP to avoid a MRRAD is used.

Any estimate of MWTP to avoid a MRRAD (or any other type of restricted activity day other than WLD) will be somewhat arbitrary because the endpoint itself is not precisely defined. Many different combinations of symptoms could presumably result in some minor or less minor restriction in activity. It has been argued (Krupnick and Kopp, 1988) that mild symptoms will not be sufficient to result in a MRRAD, so that WTP to avoid a MRRAD should exceed WTP to avoid any single mild symptom. A single severe symptom or a combination of symptoms could, however, be sufficient to restrict activity. Therefore WTP to avoid a MRRAD should, these authors argue, not necessarily exceed WTP to avoid a single severe symptom or a combination of symptoms. The "severity" of a symptom, however, is similarly not precisely defined; moreover, one level of severity of a symptom could induce restriction of activity for one individual while not doing so for another. The same is true for any particular combination of symptoms.

Given that there is inherently a substantial degree of arbitrariness in any point estimate of WTP to avoid a MRRAD (or other kinds of restricted activity days), the reasonable bounds on such an estimate are considered. By definition, a MRRAD does not result in loss of work. WTP to avoid a MRRAD should therefore be less than WTP to avoid a WLD. At the other extreme, WTP to avoid a MRRAD should exceed WTP to avoid a single mild symptom. The highest IEc midrange estimate of WTP to avoid a single symptom is $15.72, for eye irritation. The point estimate of WTP to avoid a WLD in the benefit analysis is $83. If all the single symptoms evaluated by the studies listed in Exhibit 4.5 are not severe, then the estimate of WTP to avoid a MRRAD should be somewhere between $15.72 and $83.00. Because the IEc estimate of $38.37 falls within this range (and acknowledging the degree of arbitrariness associated with any estimate within this range), the IEc estimate is used as the point estimate of MWTP to avoid a MRRAD.

Table 4-19 presents point estimates of avoided incidences of PM-related Minor Restricted Activity Days and monetary benefits associated with the five regulatory alternatives for the NOx SIP call.

Table 4-19
Avoided PM-related Minor Restricted Activity Days and Monetary Benefits
Associated with the NOx SIP Call[a]

Regulatory Alternative	Avoided Incidences (cases/year)				Monetary Benefits (millions 1990$)			
	RADM-RPM		S-R Matrix		RADM-RPM		S-R Matrix	
	15 μg/m^3	Back ground	15 μg/m^3	Back ground	15 μg/m^3	Back ground	15 μg/m^3	Back ground
0.12 Trading	1,394,423	1,621,039	423,788	742,977	$53	$62	$16	$29
0.15 Trading	620,193	611,497	298,208	498,840	$24	$24	$11	$19
Regionality 1	614,892	648,058	247,195	389,994	$24	$25	$10	$15
0.20 Trading	537,468	617,173	268,453	430,935	$21	$24	$10	$17
0.25 Trading	358,285	434,783	249,224	402,875	$14	$17	$10	$16

[a] Annual baseline incidence is 780,000 days/year per 100,000 population between the ages of 18 and 65. Total annual baseline incidence for the NOx SIP call region is 1,060,597,322 days/year.

4.4 Ozone- and PM-related Welfare Effects

In addition to the effects on human health described above, reducing NOx emissions in the eastern United States will also have welfare (i.e., non-health) effects. Welfare effects cover a potentially broad range of adverse effects, including adverse impacts on plants, animals, structural materials, visibility, and ecosystem functions. Like health effects, in order to be included in a quantified monetary benefits analysis, all of the analytical links between changes in emissions and the monetary value of the effects must be available. While the required analytical components are available for certain welfare endpoints, many other likely or possible welfare categories are omitted from the analysis. The availability of information on each analytical step limits the total coverage of the welfare effects. All of the welfare benefits that are quantified and included in the benefits analysis were included in the PM and ozone NAAQS RIA. However, there have been some changes in the quantification of certain welfare effects, which are described in this section. Table 4-20 lists the welfare categories that are included in the benefits analysis.

The welfare categories included in the SIP call analysis that use the identical procedures previously used are described in the technical support document for this RIA (Abt Associates, 1998a). The remainder of this section describes aspects of the welfare analysis that are different than the ozone and PM NAAQS RIA.

Table 4-20
Quantified Ozone- and PM- Related Welfare Effects
Included in the Benefits Analysis

Welfare Effect	Pollutant	Study
Agriculture - Commodity Crops	Ozone	Mathtech, 1998
Nitrogen Deposition in Estuarine and Coastal Waters	NOx	EPA, 1998
Decreased Worker Productivity	Ozone	Crocker and Horst, 1981 and EPA, 1994
Visibility-Class I Areas (SE only)	PM	Chestnut et al., 1997
Visibility-Residential	PM	McClelland et al., 1991
Household Soiling	PM	ESEERCO, 1994

4.4.1 Commodity Agricultural Crops

The economic value associated with varying levels of yield loss for ozone-sensitive commodity crops is analyzed using a revised and updated Regional Model Farm (RMF) agricultural benefits model (Mathtech, 1998a). The RMF is an agricultural benefits model for commodity crops that account for about 75 percent of all U.S. sales of agricultural crops. The RMF explicitly incorporates exposure-response functions into microeconomic models of agricultural producer behavior. The model uses the theory of applied welfare economics to value changes in ambient ozone concentrations brought about by particular policy actions such as the NOx SIP call.

The measure of benefits calculated by the model is the net change in consumers' and producers' surplus from baseline ozone concentrations to the ozone concentrations resulting from attainment of alternative standards. Using the baseline and post-control equilibria, the model calculates the change in net consumers' and producers' surplus on a crop-by-crop basis[3]. Dollar values are aggregated across crops for each standard. The total dollar value represents a measure of the change in social welfare

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[3] Agricultural benefits differ from other health and welfare endpoints in the length of the assumed ozone season. For agriculture, the ozone season is assumed to extend from April to September. This assumption is made to ensure proper calculation of the ozone statistic used in the exposure-response functions. The only crop affected by changes in ozone during April is winter wheat.

associated with the regulatory alternative. Although the model calculates benefits under three alternative welfare measures (perfect competition, price supports, and modified agricultural policy), results presented here are based on the "perfect competition" measure to reflect recent changes in agricultural subsidy programs. Under the recently revised 1996 Farm Bill , most eligible farmers have enrolled in the program to phase out government crop price supports for the RMF-relevant crops: wheat, corn, sorghum, and cotton.

For the purpose of this analysis, the six most economically significant crops are analyzed: corn, cotton, peanuts, sorghum, soybean, and winter wheat. In the 37-state region modeled in this analysis, these crops were valued at over $70 billion in 1997. The model employs biological exposure-response information derived from controlled experiments conducted by the National Crop Loss Assessment Network (NCLAN) (Lee et al., 1996). Four main areas of the RMF have been updated to reflect the 1996 Farm Bill and USDA data projections to 2005 (the year farthest into the future for which projections are available). These four areas are yield per acre, acres harvested, production costs, and model farms. Documentation outlining the 2005 update is provided in EPA, 1997a.

Table 4-21 presents estimates of monetary benefits due to changes in the production of all six commodity crops associated with five regulatory alternatives for the NOx SIP call. Estimates for both most and least ozone sensitive crops are presented in Table 4-21. The highest benefit estimate of $415 million (assuming relatively sensitive cultivars for the 0.12 Trading alternative) is a relatively small 0.6% of the total 1997 crop value. This suggests that individual farmers are not likely to identify ozone sensitivity as a major factor in observed yield changes in the presence of other more obvious factors, such as meterology, fertilization, and pest resistance. Likewise, given the relative importance of other yield enhancing crop traits, such as pest resistence, it is unlikely that seed developers will focus on development of ozone tolerant varieties. Nonetheless, to the extent that ozone resistant cultivars are available and farmers respond to increased ozone levels by subtituting towards more ozone resistant cultivars, crop losses will be reduced.

Table 4-21
Changes in Production of Commodity Crops and Monetary Benefits Associated with the NOx SIP Call

Regulatory Alternative	**Monetary Benefits (millions 1990$)**	
	Least Sensitive Cultivars	Most Sensitive Cultivars
0.12 Trading	$53	$415
0.15 Trading	$47	$361
Regionality 1	$43	$318
0.20 Trading	$42	$312
0.25 Trading	$34	$242

AGSIM is an alternative agricultural sector model which has gained popularity in the agricultural economics field. It has been extensively peer-reviewed and it estimates a more complete set of responses to yield changes than RMF. The primary difference is that AGSIM models planted acreage as a behavioral response to yield and relative price changes, while RMF treats planted acres as a fixed factor. As a sensitivity analysis, AGSIM was run for the five regulatory alternatives to determine how AGSIM performs relative to RMF. RMF was chosen for the primary analysis because it has been extensively tested and used in previous regulatory impact analyses. For a complete description of AGSIM, see the AGSIM technical support document (Abt Associates, 1998b).

Table 4-22 presents AGSIM generated estimates of monetary benefits due to changes in the production of all six commodity crops associated with the five regulatory alternatives for the NOx SIP call. Estimates for both most and least ozone sensitive crops are presented in Table 4-22. As might be expected, differences between the results of the models are relatively small when the least sensitive cultivars are used, while differences are much larger when the most sensitive cultivars are used. Values for AGSIM exceed those from RMF by 40 to 44 percent, depending on the regulatory alternative.

Table 4-22
Sensitivity Analysis: AGSIM Generated Monetary Benefits Due to Changes in Production of Commodity Crops Associated with the NOx SIP Call

Regulatory Alternative	Monetary Benefits (millions 1990$)	
	Least Sensitive Cultivars	Most Sensitive Cultivars
0.12 Trading	$51	$595
0.15 Trading	$44	$521
Regionality 1	$38	$451
0.20 Trading	$37	$440
0.25 Trading	$29	$338

4.4.2 Commercial Forests

Any attempt to estimate economic benefits for commercial forests associated with reductions in ozone arising from implementation of the NOx SIP call is constrained by a lack of exposure-response functions for the commercially important mature trees. Although exposure-response functions have been developed for seedlings for a number of important tree species, these seedling functions cannot be extrapolated to mature trees based on current knowledge. Recognizing this limitation, a study (Pye, 1988 and deSteiger & Pye, 1990) involving expert judgment about the effect of ozone levels on percent growth change is used to develop estimates of ozone-related economic losses for commercial forest products.

An analysis by Mathtech in conjunction with the USDA Forest Service (Mathtech, 1998b) of forestry sector benefits quantifies the effect of ozone on tree growth and the demand and supply characteristics of the timber market. The estimates do not include possible non-market benefits such as aesthetic effects. Forest aesthetics is discussed qualitatively later in this chapter.

The economic value of yield changes for commercial forests was estimated using the 1993 timber assessment market model (TAMM). TAMM is a U.S. Forest Service (Adams and Haynes, 1996) spatial model of the solidwood and timber inventory elements of the U.S. forest products sector. The model provides projections of timber markets by geographic region and wood type through the year 2040. Nine regions covering the continental U.S. are included in the analysis. TAMM simulates the effects of reduced O_3 concentrations on timber markets by changing the annual growth rates of commercial forest growing-stock inventories. The model uses applied welfare economics to value changes in ambient O_3 concentrations. Specifically, TAMM calculates benefits as the net change in consumer and producer surplus from baseline O_3 concentrations to the O_3 concentrations resulting from implementation of the NOx SIP call policy.

Table 4-23 presents estimates of monetary benefits of yield changes of commercial forests associated with the five policy alternatives for the NOx SIP call. EPA did not estimate monetary benefits for all policy alternatives. Benefits for excluded alternatives can be easily estimated using a ratio of estimated benefits to a similar benefit category, such as commodity crops. Benefits for the 0.25 trading and Regionality 1 alternatives are estimated by applying the ratio of forestry to agricultural benefits for the 0.15 trading alternative, equal to 0.59, to the agricultural benefits for these two alternatives.

Because of the long harvesting cycle of commercial forests and the cumulative effects of higher growth rates, the benefits to the future economy will be much larger than the estimates reported in Table 4-23. For example, the 0.12 trading policy alternative would result in about $8.0 billion additional forest inventories by 2040. The estimated annualized benefits for this alternative, $233 million, are much lower because of smaller benefits in earlier years (i.e., the 2010 and 2020 decades) and because the higher benefits realized in later years are heavily discounted.

Table 4-23
Commercial Forest Monetary Benefits Associated with the NOx SIP Call

Regulatory Alternative	Monetary Benefits (millions 1990$)
0.12 Trading	$233
0.15 Trading	$213
Regionality 1	$188
0.20 Trading	$185
0.25 Trading	$143

4.4.3 Nitrogen Deposition

Excess nutrient loads, especially that of nitrogen, are responsible for a variety of adverse consequences to the health of estuarine and coastal waters. These effects include toxic and/or noxious algal blooms such as brown and red tides, low (hypoxic) or zero (anoxic) concentrations of dissolved oxygen in bottom waters, the loss of submerged aquatic vegetation due to the light-filtering effect of thick algal mats, and fundamental shifts in phytoplankton community structure. Direct concentration-response functions relating deposited nitrogen and reductions in estuarine benefits are not available. The preferred willingness-to-pay based measure of benefits depends on the availability of these concentration-response functions and on estimates of the value of environmental responses. Because neither appropriate concentration-response functions nor sufficient information to estimate the marginal value of changes in water quality exist at present, an avoided cost approach is used instead of willingness-to-pay to generate estuary related benefits of the NOx SIP call.

The benefits to surrounding communities of reduced nitrogen loadings resulting from various control strategies for atmospheric NOx emissions are calculated for 10 East and 2 Gulf Coast case study estuaries, and extrapolated to all 43 Eastern U.S. estuaries. The 10 East Coast case study estuaries represent approximately half of the estuarine watershed area in square miles along the East Coast. The 12 case study estuaries are chosen because of the availability of necessary data and their potential representativeness. This analysis uses the following data for each estuary: (1) total nitrogen load from all sources; (2) direct nitrogen load from atmospheric deposition to the estuary surface; (3) indirect nitrogen load from atmospheric deposition to the estuary watershed and subsequent pass-through to the estuary itself; (4) established nitrogen thresholds and reduction goals adopted by the community; and (5) costs associated with using agreed upon non-point water pollution control technologies.

Atmospheric nitrogen reductions are valued in this analysis on the basis of avoided costs associated with agreed upon controls of nonpoint water pollution sources. Benefits are estimated using an average, locally-based cost for nitrogen removal from water pollution (EPA, 1998). Valuation reflects water pollution control cost avoidance based on average cost/pound of current non-point source water pollution controls for nitrogen in three case study estuaries: Albemarle/Pamlico Sounds, Chesapeake Bay, and Tampa Bay. Taking the weighted cost/pound of these available controls assumes States will combine low cost and high cost controls, which could inflate avoided cost estimates.

In a recent advisory statement, the EPA's Science Advisory Board (SAB), charged with reviewing the benefits methodology for the §812 Prospective report on the benefits and costs of the Clean Air Act Amendments, raised concerns about the use of the avoided cost approach to value reduced ecosystem damages. Specifically, they identified a key requirement which should be met in order for avoided costs to approximate environmental benefits. This requirement is that there is a direct link between implementation of the air pollution regulation and the abandonment of a separate costly regulatory program by some other agency, i.e. a state environmental agency. Reductions in nitrogen deposition from the NOx SIP call are expected to impact estuaries all along the eastern seaboard and the Gulf Coast. Many of the estuaries in these areas are currently being targeted by nitrogen reduction programs due to current impairment of estuarine water quality by excess nutrients. Some of the largest of these estuaries, including the Chesapeake Bay, have established goals for nitrogen reduction and target dates by which these goals should be achieved. Using the best and most easily implemented existing technologies, many of the estuaries will not be able to achieve the stated goals by the target dates. For example, the Chesapeake Bay needs an additional 9,000 tons of nitrogen reductions per year and Long Island Sound needs an additional 3,500 tons of reductions per year. Meeting these additional reductions will require development of new technologies, implementation of costly existing technologies (such as stormwater controls), or use of technologies with significant implementation difficulties, such as agricultural best management practices (BMPs). Reductions in nitrogen deposition from the atmosphere due to the NOx SIP call will directly reduce the need for these additional costly controls. Thus while the NOx SIP call does not eliminate the need for nutrient management programs already in place, it may substitute for some of the incremental costs and programs (such as an agricultural BMP program) necessary to meet the nutrient reduction goals for each estuary. This then meets the SAB requirement since the NOx SIP call will directly reduce the need for elements of separate costly reduction actions.

EPA believes that the use of an avoided cost approach in this RIA is consistent with the SAB advice for appropriate use of avoided costs. The SAB did not provide direct guidance on alternative approaches to measuring the benefits of reduced nitrogen deposition to estuaries. However, EPA recognizes the fact that avoided costs do not directly measure the benefits of reduced ecological impacts due to nitrogen deposition. Thus, while avoided cost is only a proxy for benefits, and should be viewed as inferior to willingness-to-pay based measures, it is preferred to excluding any quantitative estimate of benefits for this category. Current research is underway to develop other approaches for valuing estuarine benefits, including contingent valuation and hedonic property studies. However, this research is still sparse, and does not contain sufficient information on the marginal willingness-to-pay for changes in concentrations of nitrogen (or changes in water quality or water resources as a result of changes in nitrogen concentrations). As more studies become available, more complete estimates of the commercial and ecological benefits of reduced atmospheric deposition of nitrogen can be incorporated into regulatory analyses.

The fixed capital costs for non-point controls in the case study estuaries is ranged from $0.61 to $45.27 per pound for agricultural and other rural best management practices and from $35 to $142.64 per pound for urban nonpoint source controls (stormwater controls, reservoir management, onsite disposal system changes, onsite BMPs). Using these as a base, the total fixed capital cost per pound (weighted on the basis of fractional relationship of nitrogen load controlled for the estuary goal) is calculated for each of the case-study estuaries and applied in the valuation of their avoided nitrogen load controlled. The weighted capital costs per pound for the case-study estuaries are $32.88 for Albemarle-Pamlico Sounds, $22.31 for Chesapeake Bay, and $88.25 for Tampa Bay[4]. For the purposes of this analysis, EPA assumes that estuaries that have not yet established nutrient reduction goals will utilize the same types of nutrient management programs as projected for the case study estuaries. For the other nine estuaries, an average capital cost per pound of nitrogen (from the three case-estuaries) of $47.65/lb ($105/kg) is calculated and applied; this cost may understate or overstate the costs associated with reductions in these other estuaries. The other nine estuaries generally represent smaller, more urban estuaries (like Tampa Bay), which typically have fewer technical and financial options available to control nitrogen loadings from nonpoint sources. This may result in higher control costs more similar to the Tampa Bay case. On the other hand, these estuaries may have opportunities to achieve additional point source controls at a lower costs. Also, increased public awareness of nutrification issues and technological innovation may, in the future, result in States finding lower cost solutions to nitrogen removal.

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[4] The value for Tampa Bay is not a true weighted cost per pound, but a midpoint of a range of $58.54 to $117.65 developed by Apogee Research for the control possibilities (mostly urban BMPs) in the Tampa Bay estuary.

The 12 estuaries directly analyzed represent approximately 48% of the estuarine watershed area along the East Coast (there are 43 East Coast estuaries of which 10 were in the sample, and 31 Gulf of Mexico estuaries of which 2 are in the sample). Because NOAA data indicate that approximately 89% (92.6% by watershed area plus surface area) of East Coast estuaries are highly or moderately nutrient sensitive, it is reasonable to expect that estuaries not included in this analysis would also benefit from reduced deposition of atmospheric nitrogen. Total benefits from the 12 representative estuaries are scaled-up to include the remainder of the nutrient sensitive estuaries along the East Coast (92.6% of all East Coast estuaries) on the basis of estuary watershed plus water surface area. Since the 12 representative estuaries account for 48 percent of total eastern estuarine area, estimates are scaled up by multiplying the estimate for the 12 estuaries by 2.083 and then taking 92.6 percent of this estimate to adjust for nutrient sensitivity.

All capital cost estimates are then annualized based on a 7% discount rate and a typical implementation horizon for control strategies. Based on information from the three case study estuaries, this typically ranges from 5 to 10 years. EPA has used the midpoint of 7.5 years for annualization, which yields an annualization factor of 0.1759. Non-capital installation costs and annual operating and maintenance costs are not included in these annual cost estimates. Depending upon the control strategy, these costs can be significant. Reports on the Albemarle-Pamlico Sounds indicate, for instance, that planning costs associated with control measures comprises approximately 15% of capital costs. Information received from the Association of National Estuary Programs indicates that operating and maintenance costs are about 30% of capital costs, and that permitting, monitoring, and inspections costs are about 1 to 2% of capital costs. For these reasons, the annual cost estimates may be understated.

Table 4-24 presents estimates of monetary benefits arising from the avoided costs of nitrogen removal for the 12 estuaries with directly modeled nitrogen deposition changes and for the full set of 43 East Coast estuaries including extrapolated benefits associated with five regulatory alternatives for the NOx SIP call. Estimates in Table 4-24 assume that 10 percent of nitrogen deposited over the watershed reaches the estuary, costs for non-study estuaries are equal to the average of the costs for the three case studies, and benefits are applied only to nutrient-sensitive estuaries.

Table 4-24
Monetary Benefits Associated with the NOx SIP Call from Avoided Costs of Nitrogen Removal in Eastern Estuaries

Regulatory Alternative	Monetary Benefits (millions 1990$)	
	12 Modeled Eastern Estuaries	Extrapolation to 43 Eastern Estuaries
0.12 Trading	$129	$248
0.15 Trading	$123	$238
Regionality 1	$115	$221
0.20 Trading	$109	$210
0.25 Trading	$79	$152

4.4.4 Household Soiling Damage

Welfare benefits also accrue from avoided air pollution damage, both aesthetic and structural, to architectural materials and to culturally important articles. At this time, data limitations preclude the ability to quantify benefits for all materials whose deterioration may be promoted and accelerated by air pollution exposure. However, this analysis addresses one small effect in this category, the soiling of households by particulate matter.

Assumptions regarding the air quality indicator are necessary to evaluate the concentration-response function. PM_{10} and $PM_{2.5}$ are both components of TSP. However, it is not clear which components of TSP cause household soiling damage. The Criteria Document cites some evidence that smaller particles may be primarily responsible, in which case these estimates are conservative.

Several studies have provided estimates of the cost to households of PM soiling. The study that is cited by ESEERCO (1994) as one of the most sophisticated and is relied upon by EPA in its 1988 Regulatory Impact Analysis for SO_2 is Manuel et al. (1982). Using a household production function approach and household expenditure data from the 1972-73 Bureau of Labor Statistics Consumer Expenditure Survey for over twenty cities in the United States, Manuel et al. estimate the annual cost of cleaning per $\mu g/m^3$ PM per household as \$1.26 (\$0.48 per person times 2.63 persons per household). This estimate is low compared with others (e.g., estimates provided by Cummings et al., 1981, and Watson and Jaksch, 1982, are about eight times and five times greater, respectively). The ESEERCO report notes, however, that the Manuel estimate is probably downward biased because it does not include the time cost of do-it-yourselfers. Estimating that these costs may comprise at least half the cost of PM-related cleaning costs, they double the Manuel estimate to obtain a point estimate of \$2.52 (reported by ESEERCO in 1992 dollars as \$2.70).

Table 4-25 presents estimates of monetary benefits arising from the avoided household soiling associated with the five regulatory alternatives for the NOx SIP call. Household soiling benefits are not affected by the threshold assumption.

Table 4-25
Monetary Benefits from Reduced Household Soiling Associated with the NOx SIP Call

Regulatory Alternative	Monetary Benefits (millions 1990$)	
	RADM-RPM	S-R Matrix
0.12 Trading	$26	$11
0.15 Trading	$10	$7
Regionality 1	$10	$6
0.20 Trading	$10	$6
0.25 Trading	$7	$6

4.4.5 Visibility

Visibility effects are measured in terms of changes in deciview, a measure useful for comparing the effects of air quality on visibility across a range of geographic locations. This measure is directly related to two other common visibility measures: visual range (measured in km) and light extinction (measured in km^{-1}). The deciview measure characterizes visibility in terms of perceptible changes in haziness independent of baseline conditions. Based on the deciview measure, two types of valuation estimates are applied to the expected visibility changes: residential visibility and recreational visibility.

Visibility is a function of the ability of gases and aerosols to scatter and absorb light. RPM only computes the loss of visibility due to sulfates, nitrates, organic matter, and elemental carbon, but not other variables, such as coarse PM and fine soil. By not including these other terms, the resulting estimates of WTP for residential and recreational visibility improvement are overestimated. Based on the full suite of variables available at IMPROVE sites, the WTP estimates should, on average, be multiplied by 0.82 to correct for this bias. The range of correction factors is from 0.40 to 1.00, depending on the site and to a lesser extent the policy alternative. Similarly, when calculating residential visibility, the S-R matrix estimate includes terms for sulfates, nitrates and coarse PM, but does not include organic matter and other variables. The results from the IMPROVE monitors suggest that to correct this bias, the WTP estimates should be multiplied by 0.65 at the mean, with the correction factors ranging from 0.28 to 1.00. Note that the S-R matrix *recreational* visibility estimates include the full suite of visibility variables, so no correction is necessary.

Residential Visibility

The residential visibility valuation estimate is derived from the results of an extensive visibility study (McClelland et al., 1991). A household WTP value is derived by dividing the value reported in McClelland et al. by the corresponding hypothesized change in deciview, yielding an estimate of $14 per unit change in deciview. This WTP value is applied to all households in any area estimated to experience a change in visibility.

Table 4-26 presents estimates of monetary benefits arising from improvements in residential visibility due to reductions in PM associated with the five regulatory alternatives for the NOx SIP call. Table 4-26 includes both unadjusted visibility values and values adjusted based on the average adjustment factor Of 0.82 for the RADM-RPM set and 0.65 for the S-R Matrix set.

Table 4-26
Monetary Benefits from Improved Residential Visibility Associated with the NOx SIP Call

Regulatory Alternative	Monetary Benefits (millions 1990$)			
	RADM-RPM		S-R Matrix	
	Unadjusted	Adjusted	Unadjusted	Adjusted
0.12 Trading	$144	$118	$92	$60
0.15 Trading	$34	$28	$59	$38
Regionality 1	$42	$34	$41	$27
0.20 Trading	$46	$38	$48	$31
0.25 Trading	$30	$25	$46	$30

Recreational Visibility

The value of visibility improvements in certain National Parks in the Southeast is based on the results of a 1990 Cooperative Agreement project jointly funded by the EPA and the National Park Service, "Preservation Values For Visibility Protection at the National Parks". Based on that contingent valuation study of visibility improvements, Chestnut (1997) calculates a household willingness to pay (WTP) for visibility improvements, capturing both use and non-use recreational values, and accounts for geographic variations in the willingness to pay. This method was used in the PM and ozone NAAQS RIA analysis, and is adopted for the SIP call benefits analysis.

The Preservation Values study examined the demand for visibility in three broad regions of the country, but only the Southeast region is directly relevant for the SIP call. Respondents both inside and outside the Southeast region were asked their willingness to pay to protect visibility at four National Parks in the region: Shenandoah, Mammoth Cave, Great Smoky Mountains, and Everglades National Parks. Photos from Shenandoah (the "indicator park" in the Southeast region) were provided as part of the survey instrument. Respondents were first asked for their value for preserving "only visibility at National Parks in the Southeast". They were later asked to state what portion of their stated total value was for visibility at the indicator park alone. Prior to providing their values, respondents were instructed that "These questions concern only visibility at national parks in the Southeast and assume there will be no change in visibility at national parks in other regions. Other households are being asked about visibility, human health and vegetation protection in urban areas and at national parks in other regions". Therefore, the estimated valuation functions for the Southeastern National Parks are specifically designed to be in addition to any value for urban visibility. Note that the total value of recreational visibility improvements in Southeastern National Parks is the sum of the value for indicator and non-indicator parks. The high

Southeast recreational visibility estimate applies the "in-region" value for Southeastern visibility changes to the total population inside the Southeastern region, and the "out-of-region" value for Southeastern visibility changes to all other populations in the U.S. The total in-region WTP per household is $6.50 per deciview change, while the total out-of-region WTP per household is $4 per deciview change.

To take into account the possibility that the study did not fully account for double-counting, the low Southeast recreational visibility estimate will apply values of non-Southeast residents for Southeastern National Parks to populations both in and out of the Southeast region. The out-of-region value should not include any value for improved residential visibility, because non-Southeast residents, by definition, live outside the region, and thus are not included in the Southeast residential visibility calculation.

Table 4-27 presents estimates of monetary benefits arising improvements in recreational visibility due to reductions in PM associated with the five regulatory alternatives for the NOx SIP call. Table 4-27 includes both unadjusted visibility values and values adjusted based on the average adjustment factor of 0.82 for the RADM-RPM set. As described in the beginning of this section, recreational visibility results generated using the S-R Matrix do not need to be adjusted.

Table 4-27
Monetary Benefits from Improved Visibility in National Parks in the Southeast
Associated with the NOx SIP Call

Regulatory Alternative	**Monetary Benefits (millions 1990$)**					
	RADM-RPM				**S-R Matrix**	
	Unadjusted		**Adjusted**			
	Low	High	Low	High	Low	High
0.12 Trading	$64	$77	$52	$63	$21	$22
0.15 Trading	$36	$43	$30	$35	$15	$15
Regionality 1	$40	$49	$33	$40	$11	$10
0.20 Trading	$36	$43	$30	$35	$14	$14
0.25 Trading	$28	$34	$23	$28	$12	$11

The SIP call will impact visibility at other national parks than the specific parks examined in the Preservation Values Study's Southeast region. Visibility conditions will improve at additional national parks and recreation areas in the Southeast, as well as parks in the Northeast and Midwest. The air quality model (RADM-RPM and S-R Matrix) used to estimate visibility improvements produces estimates of the improvements at all locations throughout the SIP call region. However, there are no direct valuation studies available for these other areas.

To explore the potential magnitude of the value of improved visibility outside the Preservation Values Study's Southeast region, valuation information about the demand for visibility in the Southeast from the Preservation Values study is used to approximate the value of visibility improvements at national parks outside the Southeast. In order to account for geographic variability in WTP, the Preservation Values valuation method divided the recreational areas of the United States into three regions. Separate values were estimated for households living in each region, as well as for households living in other parts of the United States for visibility improvements in each region. In-region respondents placed higher values on visibility improvements at a local recreational area than out-of-region respondents. The lowest resident and non-resident values for any national parks examined in the Preservation Values study was for visibility in the Southeast. The out-of-region values in the Southeast will be used as an approximation of the value of national parks in the Central and Northeastern U.S. that are impacted by the NOx SIP call.

For the low Central and Northeastern recreational visibility estimates, out-of-region values per household for the Southeastern non-indicator parks (equal to 60 percent of the total value per deciview, or $2.40) are used to approximate the value to populations both outside and inside the Central and Northeastern U.S. of visibility at Central and Northeastern national parks. Out-of-region values are used for both sets of populations to avoid the possibility of double-counting benefits already accounted for in the calculation of residential visibility benefits. Non-indicator park values are used to account for the fact that indicator parks in a region may have unique values relative to non-indicator parks and therefore values for these indicator parks are not appropriate to transfer to non-indicator parks. For the high Central and Northeastern recreational visibility estimates, out-of-region values per household for the Southeastern non-indicator parks are used to approximate the value to populations outside the Central and Northeastern U.S. of visibility at Central and Northeastern national parks, and in-region values per household for the Southeastern non-indicator parks are used to approximate the value to populations within the Central and Northeastern U.S. The sum of monetary benefits for Southeast and Central and Northeastern visibility benefits will be used in the calculation of total benefits.

Table 4-28 presents the recreational visibility values for national parks outside the Southeast. Table 4-28 includes both unadjusted visibility values and values adjusted based on the average adjustment factor of 0.82 for the RADM-RPM set. As described in the beginning of this section, recreational visibility results generated using the S-R Matrix do not need to be adjusted. Recreational visibility benefits are predicted to be reduced when using the S-R Matrix generated visibility changes. This is due to predicted increases in PM in Minnesota and Maine, where two of the major parks outside the Southeast are located.

Total low-end recreational visibility benefits (Southeast plus Northeast) using RADM-RPM generated visibility changes range from $24 million for the 0.25 trading alternative to $71 million for the 0.12 trading alternative. Total RADM-RPM based high-end recreational visibility benefits range from $29 million for the 0.25 trading alternative to $85 million for the 0.12 trading alternative. Total S-R Matrix based low-end recreational visibility benefits range from $5 million for the Regionality 1 alternative to $22 million for the 0.12 trading alternative. Total S-R Matrix based high-end recreational visibility benefits range from $2 million for the Regionality 1 alternative to $21 million for the 0.12 trading alternative.

Table 4-28
Monetary Benefits Associated with Visibility Changes in National Parks
Outside the Southeast in the NOx SIP Call Region

Regulatory Alternative	Monetary Benefits (millions 1990$)					
	RADM-RPM				S-R Matrix	
	Unadjusted		Adjusted			
	Low	High	Low	High	Low	High
0.12 Trading	$22.8	$27.0	$18.7	$22.1	$0.5	$0.6
0.15 Trading	$13.4	$15.9	$11.0	$13.0	$-5.4	$-6.4
Regionality 1	$7.1	$8.5	$5.8	$7.0	$-6.5	$-7.7
0.20 Trading	$8.3	$9.8	$6.8	$8.0	$-5.8	$-6.9
0.25 Trading	$1.3	$1.6	$1.1	$1.3	$-5.2	$-6.2

4.5 Total Benefits

The dollar benefits from reducing ozone and PM levels resulting from implementing the SIP call NOx reductions is the sum of dollar benefits from the reductions in incidence of all non-overlapping health and welfare endpoints associated with PM and ozone for a given set of assumptions. If two endpoints are overlapping, then adding the benefits associated with each will result in double counting of some benefits. Although study-specific point estimates of dollar benefits associated with specific, possibly overlapping endpoints are presented separately, estimation of total benefits requires that the benefits from only non-overlapping endpoints be included in the total. Four non-overlapping broad categories of health and welfare endpoints will be included in the estimation of total dollar benefits for the SIP call: (1) mortality, (2) hospital admissions, (3) respiratory symptoms/illnesses not requiring hospital admission, and (4) welfare endpoints. When considering only point estimates, aggregation of the benefits from different endpoints is relatively straightforward. Once a set of non-overlapping categories is determined, the point estimate of the total benefits associated with the health and welfare endpoints in the set is just the sum of the endpoint-specific point estimates. If each endpoint-specific point estimate is the mean of a distribution of dollar benefits associated with that endpoint, then the point estimate of total dollar benefits is just the sum of those means.

There is uncertainty about the magnitude of the total monetized benefits associated with any of the SIP call regulatory alternatives examined in the benefits analysis. The benefits are uncertain because there is uncertainty surrounding each of the factors that affect these benefits: the changes in ambient pollutant concentrations that will result from the SIP call implementation; the relationship between these changes in pollutant concentrations and each of the associated health and welfare endpoints; and the value of each adverse health and welfare effect avoided by the reduction in pollutant concentrations.

Much of the uncertainty derives from uncertainty about the true values of analysis components, such as the value of the ozone coefficient in a concentration-response function relating ozone to a particular health endpoint, or the true dollar value of an avoided hospital admission for congestive heart failure. The analysis relies on estimates of these parameters, but the true values being estimated are unknown. This type of uncertainty can often be quantified. For example, the uncertainty about pollutant coefficients is typically quantified by reported standard errors of the estimates of the coefficients in the concentration-response functions estimated by epidemiological studies. Appendix A presents a formal quantitative analysis of the statistical uncertainty imparted to the benefits estimates by the variability in the underlying concentration-response and valuation functions.

Some of the uncertainty surrounding the results of a benefits analysis, however, involves basically discrete choices and is less easily quantified. For example, the decision of which air quality model to use to generate changes in ambient PM concentrations is a choice between two models, embodying discrete sets of air chemistry and mathematical assumptions. Decisions and assumptions must be made at many points in an analysis in the absence of complete information. The estimate of total benefits is sensitive to the decisions and assumptions made. Among the most critical of these are the following:

- **Ozone mortality:** There is some uncertainty surrounding the existence of a relationship between tropospheric ozone exposure and premature mortality. The two possible assumptions are: (1) that there is no relationship between ozone and mortality; and (2) that there is a potential relationship between ozone and mortality, which we can quantify based on the meta-analysis of current U.S. ozone mortality studies.

- **Ozone agriculture effects:** The existing set of exposure-response functions relating crop yields to changes in ozone exposure include both ozone-sensitive and ozone-insensitive cultivars. Possible assumptions are: (1) plantings of commodity crop cultivars are primarily composed of sensitive varieties; (2) plantings of commodity crop cultivars are primarily composed of non-sensitive varieties.

- **$PM_{2.5}$ concentration threshold:** Health effects are measured only down to the assumed ambient concentration threshold. Changes in air quality below the threshold will have no impact on estimated benefits. EPA's Science Advisory Board has recommended examining alternative thresholds, including background and 15 $\mu g/m^3$.

- **Sulfate Dominance:** There are two possible interpretations of PM-related health and welfare benefits depending on the model used to assess air quality changes: (1) results generated with RADM-RPM are indicative of a future eastern U.S. atmosphere where acid sulfate levels are still high enough to control atmospheric chemistry, and more specifically ammonium nitrate particle formation. In this circumstance, reductions in NOx emissions may result in non-linear responses in total fine particle levels, involving both decreases and increases; and (2) results generated with the Source-Receptor Matrix are indicative of a future eastern U.S. atmosphere where acid sulfate levels do not dominate particle formation chemistry. In this case, reductions in NOx emissions would be expected to result more directly in linear reductions in PM.

- **Recreational visibility:** Recreational visibility benefits for residents of the Southeast may overlap with "residential" visibility benefits. Two alternative assumptions may be considered for in-region residents: (1) recreational visibility benefits overlap with residential visibility benefits, and to avoid this overlap, the recreational visibility value of $4 per deciview for out-of-region residents is used for *in-region* residents ($2.40 for non-indicator parks, and $1.60 for the indicator park); or (2) recreational visibility benefits are in addition to residential visibility benefits, and the in-region value of $6.50 is used ($3.25 for non-indicator parks, and $3.25 for the indicator park).

  Benefits from visibility improvements may also occur in NOx SIP call states outside of the Southeast. The current literature on the value of recreational visibility in national parks is limited to studies of values in California, the Southwest, and the Southeast, and thus excludes the Central and Northeast (CNE) portion of the NOx SIP call region. Three alternative assumptions may be considered when valuing visibility changes in the CNE: (1) recreational visibility values in the CNE are much less than that in the Southeast and therefore to insure benefits are not overstated, no value should be associated with visibility changes in the CNE; (2) recreational visibility values in the CNE are similar to the values for non-indicator parks in the Southeast, *and* recreational and residential benefits *overlap*: people in and out of the CNE region value CNE recreational visibility at $2.40 per deciview; or (3) recreational visibility values in the CNE are similar to the values for non-indicator parks in the Southeast, and there is *no overlap* of recreational and residential benefits: the in-region CNE value is based on the Southeast in-region value of $3.25 per deciview, and the out-of-region CNE value is based on the Southeast out-of-region value of $2.40 per deciview.

Tables 4-29 through 4-33 present summaries of the endpoint specific monetary values and the estimate of total benefits for each of the five regulatory alternatives. Aggregate results are presented for two assumption sets: 1) a "low" assumption set reflecting the assumptions that human health and the environment have low responsiveness to changes in ambient air quality, and 2) a "high" assumption set reflecting the assumptions that human health and the environment are highly responsive to changes in ambient air quality. The "low" assumption set includes the following assumptions: 1) there are no PM-related health effects occurring below a threshold of 15 $\mu g/m^3$, 2) changes in PM concentrations are more accurately represented by the RADM-RPM air quality model, 3) there is no relationship between ozone and premature mortality, 4) agricultural commodity crops are less sensitive to ozone, 5) Southeastern recreational visibility values are not transferable to changes in recreational visibility in the Northeast and Central U.S., and 6) the low-end recreational visibility valuation method is correct. The "high" assumption set includes the following assumptions: 1) PM-related health effects occur down to the anthropogenic background threshold, 2) changes in PM concentrations are more accurately represented by the S-R Matrix air quality model, 3) the relationship between ozone and premature mortality is characterized by the distribution of avoided incidences derived from the ozone mortality meta-analysis, 4) agricultural commodity crops are more sensitive to ozone, 5) Southeastern recreational visibility values are transferable to the Northeastern and Central U.S., and 6) the high-end recreational visibility method is correct.

Table 4-29
Total Quantified Monetary Benefits Associated with the NOx SIP Call, Incremental to the 2007 Base Case: 0.12 Trading Regulatory Alternative[a]

Endpoint	Monetary Benefits (million 1990$)	
	"Low" Assumption Set	"High" Assumption Set
Ozone-related Endpoints		
Short-term mortality	$0	$1,496
Hospital admissions	$5	$5
Acute respiratory symptoms	$1	$1
Worker productivity	$25	$25
Commodity crops	$53	$415
Commercial forests	$233	$233
PM-related Endpoints		
Long-term mortality	$1,468	$2,672
Hospital admissions	$3	$4
Chronic bronchitis	$589	$245
Acute bronchitis	$0	$0
Acute respiratory symptoms	$0	$0
Work loss days	$14	$8
MRADs	$53	$29
Household soiling	$26	$11
Residential visibility	$118	$60
Recreational visibility	$52	$21
Nitrogen deposition	$248	$248
TOTAL	**$2,888**	**$5,473**

[a] Not all possible benefits are quantified and monetized in this analysis. Potential benefit categories that have not been quantified and monetized are listed in Table 4-2.

Table 4-30
Total Quantified Monetary Benefits Associated with the NOx SIP Call, Incremental to the 2007 Base Case: 0.15 Trading Regulatory Alternative[a]

Endpoint	Monetary Benefits (million 1990$)	
	"Low" Assumption Set	"High" Assumption Set
Ozone-related Endpoints		
Short-term mortality	$0	$1,326
Hospital admissions	$4	$4
Acute respiratory symptoms	$1	$1
Worker productivity	$22	$22
Commodity crops	$47	$361
Commercial forests	$213	$213
PM-related Endpoints		
Long-term mortality	$251	$1,763
Hospital admissions	$1	$4
Chronic bronchitis	$225	$160
Acute bronchitis	$0	$0
Acute respiratory symptoms	$0	$0
Work loss days	$6	$5
MRADs	$24	$19
Household soiling	$10	$7
Residential visibility	$28	$38
Recreational visibility	$30	$9
Nitrogen deposition	$238	$238
TOTAL	**$1,100**	**$4,170**

[a] Not all possible benefits are quantified and monetized in this analysis. Potential benefit categories that have not been quantified and monetized are listed in Table 4-2.

Table 4-31
Total Quantified Monetary Benefits Associated with the NOx SIP Call, Incremental to the 2007 Base Case: Regionality 1 Regulatory Alternative[a]

Endpoint	Monetary Benefits (million 1990$)	
	"Low" Assumption Set	"High" Assumption Set
Ozone-related Endpoints		
Short-term mortality	$0	$1,191
Hospital admissions	$4	$4
Acute respiratory symptoms	$1	$1
Worker productivity	$20	$20
Commodity crops	$43	$318
Commercial forests	$188	$188
PM-related Endpoints		
Long-term mortality	$317	$1,326
Hospital admissions	$1	$4
Chronic bronchitis	$236	$122
Acute bronchitis	$0	$0
Acute respiratory symptoms	$0	$0
Work loss days	$6	$4
MRADs	$24	$15
Household soiling	$10	$6
Residential visibility	$34	$27
Recreational visibility	$33	$10
Nitrogen deposition	$221	$221
TOTAL	**$1,138**	**$3,457**

[a] Not all possible benefits are quantified and monetized in this analysis. Potential benefit categories that have not been quantified and monetized are listed in Table 4-2.

Table 4-32
Total Quantified Monetary Benefits Associated with the NOx SIP Call, Incremental to the 2007 Base Case: 0.20 Trading Regulatory Alternative[a]

Endpoint	Monetary Benefits (million 1990$)	
	"Low" Assumption Set	"High" Assumption Set
Ozone-related Endpoints		
Short-term mortality	$0	$1,108
Hospital admissions	$4	$4
Acute respiratory symptoms	$1	$1
Worker productivity	$20	$20
Commodity crops	$42	$312
Commercial forests	$185	$185
PM-related Endpoints		
Long-term mortality	$370	$1,499
Hospital admissions	$1	$4
Chronic bronchitis	$216	$135
Acute bronchitis	$0	$0
Acute respiratory symptoms	$0	$0
Work loss days	$5	$4
MRADs	$24	$17
Household soiling	$10	$6
Residential visibility	$38	$31
Recreational visibility	$30	$7
Nitrogen deposition	$210	$210
TOTAL	**$1,156**	**$3,543**

[a] Not all possible benefits are quantified and monetized in this analysis. Potential benefit categories that have not been quantified and monetized are listed in Table 4-2.

Table 4-33
Total Quantified Monetary Benefits Associated with the NOx SIP Call, Incremental to the 2007 Base Case: 0.25 Trading Regulatory Alternative[a]

Endpoint	Monetary Benefits (million 1990$)	
	"Low" Assumption Set	"High" Assumption Set
Ozone-related Endpoints		
Short-term mortality	$0	$824
Hospital admissions	$3	$3
Acute respiratory symptoms	$1	$1
Worker productivity	$14	$14
Commodity crops	$34	$242
Commercial forests	$143	$143
PM-related Endpoints		
Long-term mortality	$208	$1,400
Hospital admissions	$1	$4
Chronic bronchitis	$148	$127
Acute bronchitis	$0	$0
Acute respiratory symptoms	$0	$0
Work loss days	$4	$4
MRADS	$14	$16
Household soiling	$7	$6
Residential visibility	$25	$30
Recreational visibility	$23	$5
Nitrogen deposition	$152	$152
TOTAL	**$777**	**$2,971**

[a] Not all possible benefits are quantified and monetized in this analysis. Potential benefit categories that have not been quantified and monetized are listed in Table 4-2.

4.6 Limitations of the Analysis

Given incomplete information, this national benefits analysis yields approximate results because of the uncertainty associated with any estimate. Potentially important sources of uncertainty exist and many of these are summarized in Table 4-34. In most cases, there is no apparent bias associated with the uncertainty. For those cases for which the nature of the uncertainty suggests a direction of possible bias, this direction is noted in the table.

4.6.1 Projected Income Growth

This analysis does not attempt to adjust benefits estimates to reflect expected growth in real income. Economic theory argues, however, that WTP for most goods (such as environmental protection) will increase if real incomes increase. The degree to which WTP may increase for the specific health and welfare benefits provided by the NOx SIP call cannot be estimated due to insufficient income elasticity information. Thus, all else being equal, the benefit estimates presented in this analysis are likely to be understated.

4.6.2 Unquantifiable Benefits

In considering the monetized benefits estimates, the reader should be aware that many limitations for conducting these analyses are mentioned throughout this RIA. One significant limitation of both the health and welfare benefits analyses is the inability to quantify many PM and ozone-induced adverse effects. Table 4-2 lists the categories of benefits that this analysis is able to quantify and those discussed only in a qualitative manner. In general, if it were possible to include the unquantified benefits categories in the total monetized benefits, the benefits estimates presented in this RIA would increase. Specific examples of unquantified benefits explored in more detail below include other human health effects, urban ornamentals, aesthetic injury to forests, nitrogen in drinking water, and brown clouds.

The benefits of reductions in a number of ozone- and PM-induced health effects have not been quantified due to the unavailability of concentration-response and/or economic valuation data. These effects include: reduced pulmonary function, morphological changes, altered host defense mechanisms, cancer, other chronic respiratory diseases, infant mortality, airway responsiveness, increased susceptibility to respiratory infection, pulmonary inflammation, acute inflammation and respiratory cell damage, and premature aging of the lungs.

Table 4-34
Sources of Uncertainty in the Benefit Analysis

1. Uncertainties Associated With Concentration-Response Functions
There is uncertainty surrounding the ozone or PM coefficient in each C-R function. There is uncertainty about applying a single C-R function to pollutant changes and populations in all locations. It is uncertain how similar future year C-R relationships will be to current concentration-response relationships. The correct functional form of each C-R relationship is uncertain. For example, it is uncertain whether there are thresholds and, if so, what they are. There is uncertainty associated with extrapolation of C-R relationships beyond the range of ozone or PM concentrations observed in the study.
2. Uncertainties Associated With Daily Ozone and PM Concentrations
There is uncertainty surrounding the projected hourly ozone and daily PM concentrations. The changes in ozone and PM concentrations resulting from the SIP call provisions are uncertain.
3. Uncertainties Associated With Possible Lagged Effects
It is uncertain what portion of the PM-related long-term exposure mortality effects associated with changes in annual PM levels would occur in a single year, and what portion might occur in subsequent years.
4. Uncertainties Associated With Baseline Incidence Rates
Some baseline incidence rates are not location-specific (e.g., those taken from studies) and may therefore not accurately represent the actual location-specific rates. It is uncertain how well current baseline incidence rates approximate what baseline incidence rates will be in the year 2007, given either "as is" ozone and PM concentrations or any alternative SIP call scenario. It is uncertain how well the projected population and demographics, used to derive incidences, approximate what the actual population and demographics will be in the year 2007.
5. Uncertainties Associated With Economic Valuation
Unit dollar values associated with health and welfare endpoints are only estimates of MWTP and therefore have uncertainty surrounding them. Possible directions of bias are discussed in the technical support document (Abt Associates, 1998a). Even using constant dollars (e.g., 1990 dollars), it is uncertain whether MWTP for each type of risk reduction will be the same in the year 2007 as the current MWTP. There is uncertainty about the appropriate discount rate for benefits achieved in the future (2007).
6. Uncertainties Associated With Aggregation of Monetized Benefits
Because benefit estimation is limited to those health and welfare endpoints for which concentration-response functions have been estimated, there may be components of total benefit omitted. This would lead to a downward bias in the estimated total monetized benefit.

In addition to the above non-monetized health benefits, there are a number of non-monetized welfare benefits of NOx emission controls from reduced adverse effects on vegetation, forests, and other natural ecosystems. The CAA and other statutes, through requirements to protect natural and ecological systems, indicate that these are scarce and highly valued resources. Lack of comprehensive information, insufficient valuation tools, and significant uncertainties result in understated welfare benefits estimates in this RIA. However, a number of expert biologists, ecologists, and economists (Costanza, 1997) argue that the benefits of protecting natural resources are enormous and increasing as ecosystems become more stressed and scarce in the future. Additionally, agricultural, forest and ecological scientists (Heck, 1997) believe that vegetation appears to be more sensitive to ozone than humans and consequently, that damage is occurring to vegetation and natural resources at concentrations below the ozone NAAQS. Experts also believe that the effect of ozone on plants is both cumulative and long-term. The specific non-monetized benefits from reductions in ambient ozone concentrations would accrue from: decreased foliar injury; averted growth reduction of trees in natural forests; maintained integrity of forest ecosystems (including habitat for native animal species); and the aesthetics and utility of urban ornamentals (e.g., grass, flowers, shrubs and trees). Other welfare categories for which there is incomplete information to estimate the economic value of reduced adverse effects include: existence value of Class I areas; materials damage; reduced sulfate deposition to aquatic and terrestrial ecosystems; and visibility impairment due to "brown clouds" (i.e., distinct brown layers of trapped air pollutants close to the ground).

Other Human Health Effects

Human exposure to PM and ozone is known to cause health effects such as: airway responsiveness, increased susceptibility to respiratory infection, acute inflammation and respiratory cell damage, premature aging of the lungs and chronic respiratory damage. An improvement in ambient PM and ozone air quality is expected to reduce the number of incidences within each effect category that the U.S. population would experience. Although these health effects are known to be PM or ozone-induced, concentration-response data is not available for quantifying the benefits associated with reducing these effects. The inability to quantify these effects leads to an underestimation of the monetized benefits presented in this analysis.

Urban Ornamentals

Urban ornamentals represent an additional vegetation category likely to experience some degree of effects associated with exposure to ambient ozone levels and likely to impact large economic sectors. In the absence of adequate exposure-response functions and economic damage functions for the potential range of effects relevant to these types of vegetation, no direct quantitative economic benefits analysis has been conducted. Ornamentals used in the urban and suburban landscape include shrubs, trees, grasses, and flowers. The types of economic losses that could potentially result from effects that have been associated with ozone exposure include: 1) reduction in aesthetic services over the realized lifetime of a plant; 2) the loss of aesthetic services resulting from the premature death (or early replacement) of an injured plant; 3) the cost associated with removing the injured plant and replacing it with a new plant; 4) increased soil erosion, 5) increased energy costs from loss of shade in the urban environment; 6) reduced seedling survivability; and 7) any additional costs incurred over the lifetime of the injured plant to mitigate the effects of ozone-induced injury. It is estimated that more than $20 billion (1990 dollars) are spent annually on landscaping using ornamentals (Abt Associates, 1995), both by private property owners/tenants and by governmental units responsible for public areas, making this a potentially important welfare effects category. However, information and valuation methods are not available to allow for plausible estimates of the percentage of these expenditures that may be related to impacts associated with ozone exposure.

Aesthetic Injury to Forests

Ozone is a regionally dispersed air pollutant that has been shown conclusively to cause discernible injury to forest trees (Fox, 1995). One of the welfare benefits expected to accrue as a result of reductions in ambient ozone concentrations in the United States is the economic value the public receives from reduced aesthetic injury to forests. There is sufficient scientific information available that ambient ozone levels cause visible injury to foliage and impair the growth of some sensitive plant species. Ozone inhibits photosynthesis and interferes with nutrient uptake, causing a loss in vigor that affects the ability of trees to compete for resources and makes them more susceptible to a variety of stresses (EPA, 1996a, p. 5-251). Extended or repeated exposures may result in decline and eventual elimination of sensitive species. Ozone concentrations of 0.06 ppm or higher are capable of causing injury to forest ecosystems.

The most notable effects of ozone on forest aesthetics and ecosystem function have been documented in the San Bernardino Mountains in California. Visible ozone-related injury, but not necessarily ecosystem effects, have also been observed in the Sierra Nevada in California, the Appalachian Mountains from Georgia to Maine, the Blue Ridge Mountains in Virginia, the Great Smoky Mountains in North Carolina and Tennessee, and the Green Mountains in Vermont (EPA, 1996a, pp. 5-250 to 5-251). These are all locations where there is substantial recreation use and where scenic quality of the forests is an important characteristic of the resource. Economic valuation studies of lost aesthetic value of forests attributed to plant injuries caused by ozone are limited to two studies conducted in Southern California (Crocker, 1985; Peterson et al., 1987). Both included contingent valuation surveys that asked respondents what they would be willing to pay for reductions in (or preventions of increases in) visible ozone injuries to plants. Crocker found that individuals are willing to pay a few dollars more per day to gain access to recreation areas with only slight ozone injury instead of areas with moderate to severe injury. Peterson et al. estimated that a one-step change (on a 5 point scale) in visible ozone injury in the San Bernardino and Angeles National Forests would be valued at an aggregate amount of between $27 million and $144 million for all residents of Los Angeles, Orange, and San Bernardino counties. A reassessment of the survey design, in light of current standards for contingent valuation research, suggests that it is plausible that concerns for forest ecosystems and human health could have been embedded into these reported values. The extent of this possible bias is uncertain.

Present analytic tools and resources preclude EPA from quantifying the benefits of improved forest aesthetics in the eastern U.S. expected to occur from the NOx SIP call. This is due to limitations in our ability to quantify the relationship between ozone concentrations and visible injury, and limited quantitative information about the value to the public of specific changes in visible aesthetic quality of forests. However, there is sufficient supporting evidence in the physical sciences and economic literature to support the finding that the proposed NOx SIP call can be expected to reduce injury to forests, and that reductions in these injuries will likely have a significant economic value to the public.

Nitrates in Drinking Water

Nitrates in drinking water are currently regulated by a maximum contaminant level (MCL) of 10 mg/L on the basis of the risk to infants of methemoglobinemia, a condition which adversely affects the blood's oxygen carrying capacity. In an analysis of pre-1991 data, Raucher, et al. (1993) found that approximately 2 million people were consuming public drinking water supplies which exceed the MCL. Supplementing these findings, the National Research Council concluded that 42 percent of the public drinking water users in the U.S. (approximately 105 million people) are either not exposed to nitrates or are exposed to concentrations below 1.3 mg/L (National Research Council, 1995).

In a recent epidemiological study by the National Cancer Institute, a statistically significant relationship between nitrates in drinking water and incidence of non-Hodgkin's lymphoma were reported (Ward, et al., 1996). Though it is generally acknowledged that traditional water pollution sources such as agricultural runoff are mostly responsible for violations of the MCL, other more diffuse sources of nitrate to drinking water supplies, such as that from atmospheric deposition, may also become an important health concern should the cancer link to nitrates be found valid upon further study.

Brown Clouds

NOx emissions, especially gaseous NO_2 and NOx aerosols, can cause a brownish color to appear in the air (EPA, 1996c). In higher elevation western cities where wintertime temperature inversions frequently trap air pollutants in atmospheric layers close to the ground, this can result in distinct brown layers. In the eastern U.S., a layered look is not as common, but the ubiquitous haze sometimes takes on a brownish hue. To date, economic valuation studies concerning visual air quality have focused primarily on the clarity of the air, and have not addressed the question of how the color of the haze might be related to aesthetic degradation. It may be reasonable to presume that brown haze is likely to be perceived as dirty air and is more likely to be associated with air pollution in people's minds. It has not, however, been established that the public would have a greater value for reducing brown haze than for a neutral colored haze. Results of economic valuation studies of visibility aesthetics conducted in Denver and in the eastern U.S. (McClelland et al., 1991) are not directly comparable because changes in visibility conditions are not defined in the same units of measure. However, the WTP estimates for improvements in visibility conditions presented in this assessment are based on estimates of changes in clarity of the air (measured as deciview) and do not take into account any change in color that may occur. It is possible that there may be some additional value for reductions in brownish color that may also occur when NOx emissions are reduced.

Other Unquantifiable Benefits Categories

There are other welfare benefits categories for which there is incomplete information to permit a quantitative assessment for this analysis. For some endpoints, gaps exist in the scientific literature or key analytical components and thus do not support an estimation of incidence. In other cases, there is insufficient economic information to allow estimation of the economic value of adverse effects. Potentially significant, but unquantified welfare benefits categories include: existence and user values related to the protection of Class I areas (e.g., Shenendoah National Park), damage to tree seedlings of more than 10 sensitive species (e.g., black cherry, aspen, ponderosa pine), non-commercial forests, ecosystems, materials damage, and reduced sulfate deposition to aquatic and terrestrial ecosystems.

Although scientific and economic data are not available to allow quantification of the effect of ozone in these categories, the expectation is that, if quantified, each of these categories would lead to an increase in the monetized benefits presented in this RIA.

4.6.3 Potential Disbenefits

In this discussion of unquantified benefits, a discussion of potential disbenefits must also be mentioned. Several of these disbenefit categories are related to nitrogen deposition while one category is related to the issue of ultraviolet light.

Passive Fertilization

Several disbenefit categories are related to nitrogen deposition. Nutrients deposited on crops from atmospheric sources are often referred to as passive fertilization. Nitrogen is a fundamental nutrient for primary production in both managed and unmanaged ecosystems. Most productive agricultural systems require external sources of nitrogen in order to satisfy nutrient requirements. Nitrogen uptake by crops varies, but typical requirements for wheat and corn are approximately 150 kg/ha/yr and 300 kg/ha/yr, respectively (NAPAP, 1990). These rates compare to estimated rates of passive nitrogen fertilization in the range of 0 to 5.5 kg/ha/yr (NAPAP, 1991). So, for these crops, deposited nitrogen could account for as much as 2 to 4 percent of nitrogen needs. Holding all other factors constant, farmers' use of purchased fertilizers or manure may increase as deposited nitrogen is reduced. EPA has not estimated the potential value of this possible increase in the use of purchased fertilizers, but a qualitative assessment of several factors suggests that the overall value is very small relative to the value of other health and welfare endpoints presented in this analysis. First, reductions in NOx emissions affect only a fraction of total nitrogen deposition. Approximately 70 to 80 percent of nitrogen deposition is in the form of nitrates (and thus can be traced to NOx emissions) while most of the remainder is due to ammonia emissions (personal communication with Robin Dennis, NOAA Atmospheric Research Lab, 1997). Table 3-4 in Chapter 3 indicates the annual average change in nitrogen deposition attributable to the 0.15 Trading alternative of the NOx SIP call is about 11 percent of baseline levels, suggesting a relatively small potential change in passive fertilization. Second, some sources of nitrogen, such as animal manure, are available at no cost or at a much lower cost than purchased nitrogen. In addition, in certain areas nitrogen is currently applied at rates which exceed crop uptake rates, usually due to an overabundance of available nutrients from animal waste. Small reductions in passive fertilization in these areas is not likely to have any consequence to fertilizer application. The combination of these factors suggests that the cost associated with compensating for reductions in passive fertilization is relatively minor.

Information on the effects of changes in passive nitrogen deposition on forestlands and other terrestrial ecosystems is very limited. The multiplicity of factors affecting forests, including other potential stressors such as ozone, and limiting factors such as moisture and other nutrients, confound assessments of marginal changes in any one stressor or nutrient in forest ecosystems. However, reductions in deposition of nitrogen could have negative effects on forest and vegetation growth in ecosystems where nitrogen is a limiting factor (EPA, 1993).

On the other hand, there is evidence that forest ecosystems in some areas of the United States are nitrogen saturated (EPA, 1993). Once saturation is reached, adverse effects of additional nitrogen begin to occur such as soil acidification which can lead to leaching of nutrients needed for plant growth and mobilization of harmful elements such as aluminum. Increased soil acidification is also linked to higher amounts of acidic runoff to streams and lakes and leaching of harmful elements into aquatic ecosystems.

Ultraviolet Light

A reduction of tropospheric ozone is likely to increase the penetration of ultraviolet light, specifically UV-b, to ground level. UV-b is an issue of concern because depletion of the stratospheric ozone layer (i.e., ozone in the upper atmosphere) due to chlorofluorocarbons and other ozone-depleting chemicals is associated with increased skin cancer and cataract rates. Currently, EPA is not able to adequately quantify these effects for the purpose of valuing benefits for this policy.

Other EPA programs exist to address the risks posed by changes in UV-b associated with changes in total column ozone. As presented in the Stratospheric Ozone RIA (EPA, 1992), stratospheric ozone levels are expected to significantly improve over the next century as the major ozone depleting substances are phased out globally. This expected improvement in stratospheric ozone levels is estimated to reduce the number of nonmelanoma skin cancers (NMSC's) by millions of cases in the U.S. by 2075.

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Chapter 5. BENEFIT-COST COMPARISONS

This Regulatory Impact Analysis (RIA) provides cost, economic impact, and benefit estimates that are potentially useful for evaluating alternative policy options for the NOx SIP call. Benefit-cost analysis provides a systematic framework for assessing and comparing such alternatives. According to economic theory, the efficient alternative maximizes net benefits to society (i.e., social benefits minus social costs). However, there are practical limitations for the comparison of benefits to costs in this analysis. This chapter also discusses the key limitations and uncertainties associated with the benefit and cost estimates. Nonetheless, if one is mindful of these limitations, the relative ordering and magnitude of the benefit-cost comparisons presented here can be useful policy information.

5.1 Summary of Cost Estimates

This section provides a summary of cost results presented in Volume 1 of this RIA. Table 5-1 summarizes the total annual control cost estimates developed in this analysis for the year 2007 for a selected set of regulatory alternatives that closely approximate the alternatives analyzed in the benefits analysis. These costs include potential changes in the nationwide costs of electricity generation for the network of electricity generating sources (EGUs), direct control costs to potentially affected non-EGU sources, emissions monitoring costs associated with the administrative costs associated with monitoring The majority of the total annual cost is due to control on electricity generating units (EGUs) for each alternative.

Table 5-1
Estimated Total Annual Cost of NOx SIP Call Alternatives in 2007

Regulatory Alternative	Total Annual Costs (million 1990$)
0.12 Trading 60%/$5,000	$2,128
0.15 Trading 60%/$5,000	$1,660
Regionality 1 60%/$5,000	$1,400
0.20 Trading 60%/$5,000	$1,230
0.25 Trading 60%/$5,000	$925

5.2 Summary of Benefits Estimates

Table 5-2 summarizes the total annual benefits developed in this analysis for the year 2007 for the "plausible range" of assumptions. Not all possible benefits are quantified and monetized in this analysis. Potential benefit categories that have not been quantified and monetized are listed in Table 4-2 in Chapter 4 of Volume 2 of this RIA.

Table 5-2
"Plausible Range" of Annual Quantified Benefits Estimates
for NOx SIP Call Alternatives in 2007
(million 1990$) [a]

Regulatory Alternative	Annual Quantified Benefits--"Low" Assumption Set	Annual Quantified Benefits--"High" Assumption Set
0.12 Trading 60%/$5,000	$2,888	$5,473
0.15 Trading 60%/$5,000	$1,100	$4,170
Regionality 1 60%/$5,000	$1,138	$3,457
0.20 Trading 60%/$5,000	$1,156	$3,543
0.25 Trading 60%/$5,000	$777	$2,971

[a] Not all possible benefits are quantified and monetized in this analysis. Potential benefit categories that have not been quantified and monetized are listed in Table 4-2 in Chapter 4 of this RIA.

5.3 Summary of Net Benefits

Table 5-3 summarizes the total annual quantifiable net benefits for NOx SIP call regulatory alternatives for the year 2007. There are several conclusions that can be drawn from Table 5-3.

- For the "High" assumption set, monetized net benefits are positive and substantial for all regulatory alternatives.
- As modeled, Regionality 1 is an inferior alternative, i.e., even though 0.20 Trading is less stringent it achieves greater benefits at lower total costs.
- Net benefits are greatest at the most stringent regulatory alternative evaluated, i.e., 0.12 Trading. For the "High" assumption set, net benefits are approximately 33 percent higher for the 0.12 Trading relative to the 0.15 Trading alternative. For the "Low" assumption set, net benefits are positive only for the 0.12 Trading alternative.

- While net benefits are negative for the "Low" assumption set for all but the 0.12 Trading alternative, it is important to remember that while all of the costs are included, many benefit categories could not be quantified. In addition, the "Low" assumption set estimate assumes that there are no reductions in premature mortality associated with ozone reductions. Relaxing this one assumption would result in positive net benefits for all alternatives at the low end.

Table 5-3
Estimated Annual Quantified Net Benefits[a]
for NOx SIP Call Alternatives in 2007
(million 1990$)

Regulatory Alternative	Quantified Net Benefits-- "Low" Assumption Set	Quantified Net Benefits-- "High" Assumption Set
0.12 Trading 60%/$5,000	$760	$3,345
0.15 Trading 60%/$5,000	($560)	$2,510
Regionality 1 60%/$5,000	($262)	$2,057
0.20 Trading 60%/$5,000	($74)	$2,313
0.25 Trading 60%/$5,000	($148)	$2,046

[a] Calculated as quantified benefits minus costs. Not all possible benefits are quantified and monetized in this analysis. Potential benefit categories that have not been quantified and monetized are listed in Table 4-2 in Chapter 4 of this volume of the RIA.

5.4 Limitations to the Benefit-Cost Comparison

Cost-benefit analysis provides a valuable framework for organizing and evaluating information on the effects of environmental programs. When used properly, cost-benefit analysis helps illuminate important potential effects of alternative policies. However, not all potential costs and benefits can be captured in any analysis, and there always the issue of how much technological changes will lower future pollution abatement costs, or change the nature of compliance actions by the regulated community over time. EPA is generally able to estimate reasonably well the costs of pollution controls based on today's control technology and assess the important impacts when it has sufficient information for its analysis. EPA is developing an increasing ability to estimate benefits associated with changes in emissions, but EPA believes that there are many important benefits that it can not quantify or monetize that are associated with the NOx SIP call, including many health and welfare effects. Potential benefit categories that have not been quantified and monetized are listed in Table 4-2 in Chapter 4 of this volume of the RIA and should be remembered in comparing the above quantitative benefits.

Several other important limitations deserve to be mentioned:

- The state of atmospheric modeling is not sufficiently advanced to provide a workable "one atmosphere" model capable of characterizing ground-level pollutant exposure for all pollutants of interest (e.g., ozone, particulate matter, carbon monoxide, nitrogen deposition, etc). Therefore, EPA must employ several different pollutant models to characterize the effects of alternative policies on relevant pollutants. Also, not all atmospheric models have been widely validated against actual ambient data. In particular, since a broad-scale monitoring network does not yet exist for fine particulate matter ($PM_{2.5}$), atmospheric models designed to capture the effects of alternative policies on $PM_{2.5}$ are not fully validated. The Agency has chosen the best available models for the application needs of this RIA and tried to make the most reasonable assumptions possible in using them for predicting air quality changes. Limitations are noted in appropriate areas of the RIA.

- There are limitations in some aspects of the data that are available to perform these analyses. These limitations have been identified along the way in this RIA. While they exist, EPA believes that it has used all models and assumptions in this analysis in a reasonable way based on the available evidence. Qualitative and more detailed discussions of the above and other uncertainties and limitations are included in the analysis. Where information and data exists, quantitative characterizations of these uncertainties are included. An illustrative example of how one aspect of uncertainty can be quantified is provided in Appendix A of Volume 2. However, data limitations prevent an overall quantitative estimate of the uncertainty associated with final estimates. Nevertheless, the reader should keep all of these uncertainties and limitations in mind when reviewing and interpreting the results.

- Another dimension adding to the uncertainty of the results is the potential for pollution control innovations that can occur over time. For the NOx SIP call, EPA expects that the most significant costs of this regulation (i.e., the costs associated with installation and operation of NOx pollution control equipment at coal-fired electricity generating units throughout the SIP call region) will occur by May 2003. The Agency is aware of some innovations that equipment vendors are considering now for application at some units before 2003 that are not part of the cost analyses presented in Volume 1. These innovations include the possible use of SCR and SNCR in hybrid technologies, or improved combustion controls beyond what vendors have installed in the past that could be used with and without the addition of post-combustion control technology. It is impossible to anticipate exactly how much of an impact, if any, these new technologies may have in lowering the compliance costs for the NOx SIP call in the future. Their possible influence can only be recognized.

- There is also the uncertainty over future costs due to the flexibility afforded by an emissions cap-and-trade program that EPA is encouraging the States to set up under this rule. The analysis that EPA has completed to date has been fairly conservative--the analysis of the electric power industry and large industrial boilers and combustion turbines assumes these sources operate under separate trading programs. In reality, they should enter the same trading pool and there should be greater efficiency resulting from their ability to trade NOx emissions allowances with each other. There is also the possibility of

> unforeseen innovation, which a cap-and-trade program fosters, since it allows the regulated community to work out the best approaches to future compliance. Therefore, the Agency believes that its cost analysis is a reasonably conservative estimate of the future compliance costs that will occur if States enter into the trading program that the Agency has described in the Model NOx Budget Trading Rule as part of the NOx SIP call rule. If some States do not enter the program, any inefficiencies that result for the regulated community in those States should not be viewed as a cost of this rule.

Despite the above limitations and uncertainties, EPA believes that the analysis provided in this report provides the Agency with a basis for believing that in the year 2007, benefits resulting from the regulatory alternatives that EPA analyzed for NOx SIP call will be up to two and one-half times costs.

5.5 References

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APPENDICES

to the

REGULATORY IMPACT ANALYSIS FOR THE NOx SIP CALL, FIP, AND 126 PETITIONS

Volume 2: Health and Welfare Benefits

Appendix A. QUANTIFIED UNCERTAINTY IN HEALTH AND WELFARE BENEFITS

A.1 Overview

Chapter 4 presents point estimates of the monetary benefits associated with each health and welfare endpoint. For most endpoints, an estimate of the statistical uncertainty range based on measured variability in the underlying health effects and valuation components of the analysis can also be computed. Uncertainty regarding other aspects of the analysis (such as emissions and resulting air quality) is not included in the uncertainty analysis, resulting in a likely underestimate of the overall uncertainty of the monetized benefits for each category.

The two sources of uncertainty that are quantified in the NOx SIP call benefits analysis are the uncertainty about the concentration-response functions (and thus about changes in incidence) and the uncertainty about mean willingness to pay for each unit change in incidence (i.e., unit dollar values). The total dollar benefit associated with a given endpoint depends on how much the endpoint will change if a given NOx SIP call alternative is implemented (e.g., how many premature deaths will be avoided) and how much each unit of change is worth (e.g., how much a premature death avoided is worth). Not all endpoints have quantified uncertainty for both the concentration-response function and valuation function

The uncertainty about each component is characterized by a *distribution* of values that the component might have. This distribution is essentially a Bayesian posterior distribution, based on the available information. A distribution of possible incidence changes and a distribution of possible unit dollar values for each endpoint is constructed from available information whenever possible. The uncertainty about the true incidence change (or the true unit dollar value) for a given endpoint is expressed as a 90 percent credible interval. This is the interval from the fifth percentile point to the ninety-fifth percentile point of the Bayesian posterior distribution of incidence changes (or unit dollar values) for that endpoint. The 90 percent credible interval is a "credible range" within which, according to the available information (embodied in the Bayesian posterior distribution of possible values), the true value lies with 90 percent probability.

The uncertainty surrounding estimates of total monetary benefits for each endpoint is similarly characterized by a distribution of possible values, the fifth and ninety-fifth percentile points of which comprise the 90 percent credible interval of total monetary benefits for the endpoint. The distribution of total monetary benefits for an endpoint is generated from the distribution of incidence changes and the distribution of unit dollar values for that endpoint, using Monte Carlo techniques. In this procedure, on each of many iterations, a value is randomly drawn from the incidence distribution and a value is randomly drawn from the unit dollar value distribution, and the total dollar benefit for that iteration is the product of the two.[1] If this is repeated for many (e.g., thousands of) iterations, an estimate of the distribution of total

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[1] This method assumes that the incidence change and the unit dollar value for an endpoint are stochastically independent.

dollar benefits associated with the endpoint is generated[2]. The mean of this Monte Carlo-generated distribution is presented as the point estimate of total monetary benefits for the endpoint. As the number of Monte Carlo draws gets larger and larger, the Monte Carlo-generated distribution becomes a better and better approximation to the underlying Bayesian distribution of total monetary benefits. In the limit, it is identical to the underlying distribution, and its mean, presented as the point estimate, is identical to the mean of the underlying distribution of total monetary benefits for the endpoint.

The distributions of unit dollar values for those health and welfare endpoints considered in this uncertainty analysis, and the means of those distributions, are given in Table A-1 below. In addition, the means and 90 percent credible intervals (the fifth and ninety-fifth percentile points of the distributions of possible values) of avoided incidences and the corresponding means and 90 percent credible intervals of total monetary benefits associated with these endpoints can be found in the results technical support document (Abt Associates, 1998a).

A.2 Underlying Sources of Uncertainty

For most health endpoints (with the exception of ozone-related mortality and short-term PM-related mortality), the concentration-response function is obtained from a single epidemiological study. For all of these studies, the uncertainty about the unknown parameter in the concentration-response function is characterized by a normal distribution with mean equal to the estimate of the parameter value reported in the study and standard deviation equal to the standard error of the estimate reported in the study. To the extent that avoided incidence is a linear function of this concentration-response function parameter, the distribution of avoided incidence will also be normally distributed.[3]

For ozone-related mortality and short-term PM-related mortality, the distribution of incidence changes is based on a pooling of the information in several concentration-response functions. In the case of short-term PM-related mortality, the input components to the concentration-response (C-R) functions estimated in the studies (e.g., functional forms, pollutant averaging times, study populations) are all the same or very similar, so that a pooled, "central tendency" C-R function can be derived from multiple study-specific C-R functions. For ozone-related mortality, however, the pollutant averaging time is not the same across all studies. Some of the four studies measured daily 1-hour maximum ozone concentrations while others measured daily (or some other) average ozone concentrations. It is therefore not possible to pool the C-R functions to derive a central tendency "pooled" C-R function for ozone-related mortality. Instead, using the ozone data appropriate to each study (either one-hour daily maxima or daily averages), national ozone mortality incidence distributions are derived corresponding to the C-R function from each study, and these study-specific national incidence distributions are then pooled. That is, the pooling of results is done in "national incidence space" rather than in "ozone coefficient space." For a more detailed discussion of the methodology of pooling results from studies, see the report titled *Selected Health and Welfare Benefits Methods for the NOx SIP Call RIA* (Abt, Associates, September 1998b).

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[2] To improve computer efficiency, a Latin Hypercube technique is actually used for the incidence change distribution when implementing all phases of the Monte Carlo analysis.

[3] The concentration-response functions are almost linear functions of the parameter.

Construction of distributions of unit dollar values, or mean willingness to pay (MWTP) for a case avoided, is often not as straightforward to describe. Estimates of MWTP can be complicated functions of estimated parameters, for which information about the statistical distributions are not available in published studies. The assumed distributions for MWTP for each endpoint are listed in Table A-1. For a more complete description of the underlying studies and derivation of the distributions of MWTP, see Chapter 4 and the benefits technical support document (Abt Associates, 1998b). For some endpoints, while uncertainty is recognized and a range of possible values is available, there is insufficient information to construct

Table A-1
Point Estimates and Assumed Distributions of MWTP for Health and Welfare Endpoints in the NOx SIP Call Analysis

Endpoint	Point Estimate of MWTP	Derived Distribution of the Estimate of MWTP (1990$)
Mortality	$4,800,000	A Weibull distribution, Std. Dev. = $3.24 million
Chronic bronchitis	$260,000	A Monte Carlo-generated distribution, based on three underlying distributions, as described in the technical support document.
URS (as defined by Pope et al., 1991)	$19	Continuous uniform distribution over the interval [$7.00, $32,72]
LRS (as defined by Schwartz et al., 1994)	$12	Continuous uniform distribution over the interval [$5.27, $18.57]
"Presence of any of 19 acute respiratory symptoms"	$18	Continuous uniform distribution over the interval [$0.00, $36.62]
Acute Bronchitis	$45	Continuous uniform distribution over the interval [$13.29, $76.74]
Minor Restricted Activity Days (MRADs)	$38	triangular distribution centered at $38.37 on the interval [$15.72, $61.02]
Work Loss Days	$83	N.A.[a]
Worker Productivity	$1/ worker/10% change in O_3	N.A.
Visibility - Residential	$14 per unit change in dv	Triangular distribution centered at $14 on the interval [$8, $21]
Visibility - Recreational	$6.50 per unit change in dv (in-region) $4 per unit change in dv (out-of-region)	Normal distribution with std. dev. equal to 0.42 (in-region) and 0.10 (out-of-region)
Consumer Cleaning Cost Savings	$2.52 per $\mu g/m^3$ change in PM_{10} per household	Beta distribution with, std. dev.=$1.00 on the interval [$1.26, $10.08]. The shape parameters of this distribution are α=1.2 and β=7.3.

[a] "N.A." indicates that a distribution is not available.

anything other than a uniform distribution of unit dollar values, which assumes that each point in the range is equally likely.

For agricultural, forestry, and nitrogen deposition benefits, there are no distributions or ranges of unit values available. Variation in the endpoints occurs due to changes in the underlying assumptions in the models generating the benefit estimates, i.e. sensitivity of cultivars to ozone for agricultural benefits. Thus, for these endpoints, uncertainty ranges are not reported. Sensitivity to changes in the underlying assumptions can be examined through the plausible range approach, where assumptions can be grouped to form a range with low and high estimates.

A.3 Quantified Uncertainty for Ozone-related Benefits

The quantification of the uncertainty about the magnitude of the ozone mortality relationship is a very important issue in the economic benefits estimation. While the growing body of epidemiological studies suggests that there in a positive relationship between ozone and premature mortality, it is still unclear whether the apparent ozone effect on mortality is real. There is a diversity of published results and substantial measured uncertainty within each study. This high degree of uncertainty has lead to some counterintuitive "results." Based on the meta-analysis generated distribution of avoided ozone-related cases of premature mortality corresponding to the NOx SIP call estimated future air quality, there is approximately a 13 percent probability that there is a negative relationship between ozone exposure and premature mortality (i.e., that elevated ozone *prevents* premature mortality). This "result" should be interpreted with caution, however. It is biologically implausible that elevated ozone levels are beneficial to human health. The portion of the estimated incidence change distribution in the negative range is most likely the result of random error in the estimation of the ozone coefficients in concentration-response functions and/or the result of modeling misspecification (the underlying models do not prevent negative results *a priori*, and the estimated coefficients are asymptotically normal, which results in a negative lower tail of the distribution). By construction, the meta-analysis distribution incorporates both between-location variability and within-location sampling error. As more studies become available, and, in particular, as newer studies incorporate information from longer periods of time and therefore have results based on more observations, the sampling error component of the meta-analysis distribution will decrease. As this occurs, the meta-analysis distributions will better approximate the underlying distributions of which they are estimates, and the portions of the distributions in the negative range are likely to diminish accordingly.

A.4 Quantified Uncertainty for PM-related Benefits

For household soiling damage and visibility, no point estimates or distributions are presented for avoided incidences. This is because PM-related household soiling is directly valued on a per household basis, rather than measuring some unit of incidence (such as hours lost) and multiplying by a value per unit. Visibility is valued on a constant percentage deciview change per household, so there are no avoided incidences. The correct unit measure is percent change in deciview, which is then input into a valuation function to get value per household, which is then summed over all households in the NOx SIP call region. Thus, uncertainty is measured in the valuation stage, but not in the generation of changes in visibility.

A.5 Statistical Uncertainty and Plausible Ranges

The tables of benefit estimates presented in Chapter 4 represent monetary benefits estimates for five NOx SIP call regulatory alternatives under the "Low" and "High" sets of assumptions regarding the PM threshold level, ozone mortality, agricultural benefits, and the PM air quality model. Benefits estimates associated with the "High" and "Low" assumption sets have corresponding statistical uncertainty ranges as well, with 5th percentile, mean, and 95th percentile estimates of benefits. As discussed in Chapter 4, the range of values from the mean of the "Low" assumption set to the mean of the "High" assumption set represents a "plausible range" across the different assumptions. However, this range does not provide information on the likelihood of any set of assumptions being the correct one. Thus, while the plausible range indicates the sensitivity of benefits to the various assumptions, it does not express the uncertainty associated with any particular benefits estimate. To understand the uncertainty associated with a particular estimate, it is necessary to know both the underlying assumption set and the statistical distribution around the estimate determined by the variance of the underlying concentration-response functions and valuation functions.

A.6 References

Abt Associates, Inc. 1998a. *Benefit Analysis Results of Selected Health and Welfare Endpoints for the NOx SIP Call RIA*, Prepared for the U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards; Research Triangle Park, N.C., September.

Abt Associates, Inc. 1998b. *Selected Health and Welfare Benefits Methods for the NOx SIP Call RIA*, Prepared for the U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards; Research Triangle Park, N.C., September.

Appendix B. SUMMARY OF POPULATION-WEIGHTED AIR QUALITY METRICS

This appendix summarizes the predicted air quality changes used in the benefits analyses for this RIA, weighted by population. The population-weighted air quality changes are calculated for several "metrics," or measures of air quality based on results of the air quality modeling described in Chapter 3. For ozone, these metrics include 1-hour and 8-hour average concentration predictions above the level of the respective health standards. For PM, the metrics include annual mean $PM_{2.5}$ and annual mean PM_{10} predictions above the level of the respective health standards. The metrics are calculated for the total population and for various subpopulations, including minority groups (represented by the Census Bureau's "non-white" category), the elderly (65 years of age and older), children (under 18 years old), and the low income group (1990 annual income under $13,359 for a family of 4). The air quality changes cover the entire area of each modeling domain; data is presented for the entire modeling domain (37 States & D.C.) and for the SIP Call region states. The population-weighted metric for modeled visibility degradation is presented in Chapter 2, Section 2.6, rather than in this appendix. A population-weighted metric is not calculated for modeled nitrogen deposition changes. Additional detail on all population-weighted metrics can be found in the report titled *Air Quality Estimation for the NOx SIP Call RIA* (Abt, Associates, September 1998).

Table B-1
2007 Population-Weighted Sum of 1-Hour Ozone Predictions Above 124 ppb[a]: Adjusted and Extrapolated UAM-V Results

Population	Percent Change from Base Case				
	0.25 Trading	0.20 Trading	Regionality 1	0.15 Trading	0.12 Trading
SIP Call States					
All Populations	-50.9	-63.0	-66.6	-69.4	-73.9
Non-White	-48.9	-61.6	-64.0	-67.8	-73.7
Under 18	-50.7	-62.8	-66.2	-69.2	-73.8
65 and over	-49.2	-61.3	-65.5	-68.4	-73.1
Low Income	-58.5	-69.0	-71.4	-73.7	-78.0
37 States & D.C.					
All Populations	-19.2	-24.1	-25.3	-26.0	-27.3
Non-White	-14.7	-18.9	-19.5	-14.7	-21.4
Under 18	-17.3	-21.7	-22.8	-17.3	-24.5
65 and over	-25.1	-31.5	-33.5	-25.1	-36.6
Low Income	-18.3	-22.1	-22.7	-18.3	-23.6

[a] The 1-hour ozone standard allows an average of 1 exceedance above 120 ppb (rounded to the nearest ppb) over a 3 year period. This analysis does not predict three years worth of air quality, and is therefore not directly comparable to the official standard.

Table B-2
2007 Population-Weighted Sum of 8-Hour Average Ozone Predictions Above 84 ppb[a]: Adjusted and Extrapolated UAM-V Results

Population	Percent Change from Base Case				
	0.25 Trading	0.20 Trading	Regionality 1	0.15 Trading	0.12 Trading
SIP Call States					
All Populations	-31.0	-39.9	-44.0	-46.8	-51.0
Non-White	-26.8	-35.4	-39.5	-42.3	-46.8
Under 18	-31.4	-40.3	-44.3	-47.2	-51.5
65 and over	-30.8	-39.7	-43.9	-46.7	-50.9
Low Income	-38.8	-48.3	-54.3	-56.7	-60.4
37 States & D.C.					
All Populations	-24.1	-31.2	-34.3	-36.5	-39.6
Non-White	-20.0	-26.4	-29.3	-31.4	-34.6
Under 18	-23.6	-30.4	-33.3	-35.5	-38.5
65 and over	-26.0	-33.6	-37.2	-39.5	-42.9
Low Income	-18.3	-22.1	-22.7	-22.5	-23.6

[a] The 8-hour ozone standard of 80 ppb (rounded to the nearest ppb) is based on each year's 4th highest daily mazimum 8-hour average ozone concentration averaged over a 3 year period. This analysis does not predict three years worth of air quality, and is therefore not directly comparable to the official standard.

Table B-3
2007 Population-Weighted Sum of Annual Mean $PM_{2.5}$ Predictions Above 15.04 µg/m^3 [a]: RPM Results

Population	Percent Change from 2007 Base Case				
	0.25 Trading	0.20 Trading	Regionality 1	0.15 Trading	0.12 Trading
SIP Call States					
All Populations	-4.6	-6.0	-6.8	-6.7	-14.5
Non-White	-4.5	-6.0	-6.5	-6.3	-14.8
Under 18	-4.6	-6.0	-6.8	-6.8	-14.5
65 and over	-4.5	-5.9	-6.8	-6.5	-14.3
Low Income	-5.4	-8.7	-11.4	-6.2	-19.1
37 States & D.C.					
All Populations	-3.0	-4.1	-4.5	-4.6	-10.0
Non-White	-3.8	-5.1	-5.5	-5.4	-12.8
Under 18	-3.0	-4.1	-4.5	-4.6	-9.9
65 and over	-2.8	-3.9	-4.4	-4.3	-9.5
Low Income	-4.4	-7.2	-9.3	-5.2	-15.9

[a] The $PM_{2.5}$ annual mean standard of 15 µg/m^3 (rounded to the nearest 1/10th) averaged over a 3 year period. This analysis is not based on an extensive network of actual $PM_{2.5}$ observations and does not predict three years worth of air quality, and is therefore not directly comparable to the official standard.

Table B-4
2007 Population-Weighted Sum of Annual Mean PM_{10} Predictions Above 50.4 $\mu g/m^3$ [a]: RPM Results [b]

Population	Percent Change from Base Case				
	0.25 Trading	0.20 Trading	Regionality 1	0.15 Trading	0.12 Trading
All Populations	-0.0	-0.0	-0.0	-0.0	-0.0
Non-White	-0.0	-0.0	-0.0	-0.0	-0.0
Under 18	-0.0	-0.0	-0.0	-0.0	-0.0
65 and over	-0.0	-0.0	-0.0	-0.0	-0.0
Low Income	-0.0	-0.0	-0.0	-0.0	-0.0

[a] The PM_{210} annual mean standard of 50 $\mu g/m^3$ (rounded to the nearest μg) averaged over a 3 year period. This analysis does not predict three years worth of air quality, and is therefore not directly comparable to the official standard.

[b] All locations have predictions below the PM10 standard, hence there are no reductions in exposures relative a 50 ug/m^3 annual mean threshold.

Appendix D. NONLINEAR CHEMISTRY AND FINE PARTICLE PRODUCTION

Evaluating the effect of major reductions in emissions of nitrogen oxides on particles in made more difficult because NOx plays an important role in the atmospheric chemistry, including formation of nitrate, organic, and sulfate particles. The extent to which NOx reductions reduce fine particle levels is dependent on a number of factors that vary with time and location, including the concentration of key reactive gases and particles, as well as emissions and meteorology. The following discussion provides some background on the nature of these chemical reactions as a basis for understanding the relevance of non-linear modeling results..

D.1 Background

The hydroxyl radical, OH, is a major oxidizing specie in the atmosphere. The largest single source of OH is the breakdown of ozone, O_3, by ultraviolet light in the presence of water. Clearly, reduction of NOx can affect the production of ozone and OH radical in particular locations. Sulfate, a major component of fine particles, is formed by the oxidation of SO_2 through two main pathways: gas-phase oxidation and aqueous-phase oxidation (in water droplets). Sulfate is formed in the gas phase by oxidation of SO_2 by OH. This process does not use up OH, by and large, so a change in SO_2 produces approximately an equivalent change in SO_4. Also, an increase/decrease in OH will cause an increase/decrease in gas-phase produced SO_4.

Sulfate (SO_4) is also formed in the aqueous phase in cloud droplets. This occurs by conversion of SO_2 by hydrogen peroxide, H_2O_2, and O_3. The vast proportion of the aqueous-phase SO_4 is produced by H_2O_2 for eastern North American conditions. This process does use up oxidants. If SO_2 is very high, then there can be oxidant-limited conditions, i.e., the nonlinearity that was of concern in NAPAP with respect to the effectiveness of acid rain controls. Under oxidant-limited conditions, the production of SO_4 will be mostly determined by the availability of the oxidant, not by the availability of SO_2. Modeling analysis with RADM estimates that a majority of the eastern U.S. sulfate comes from the aqueous-phase oxidation of sulfur dioxide, the second pathway.

Nitric acid, HNO_3, the precursor to aerosol nitrate, in formed by NO_2 combining with OH. The formation of HNO_3 is a termination reaction and uses up both OH and NO_2. This reaction is part of the photochemical process that accounts for the production of O_3.

The radicals that are produced during any one day all disappear or terminate during that day in a matter of tens of minutes. Production equals termination in the photochemical process. There are two important pathways of termination that are in constant competition:

a) OH combines with NO_2, taking out one radical. If there is a lot of NOx around, this pathway out competes and inhibits the availability of radicals by taking so many OH's out of the action so quickly. If NOx is scarce, then this pathway cannot compete as well and a second termination pathway becomes most important.

b) In the second main termination pathway, OH combines with itself, to form H_2O_2; hydroxy radicals combine with peroxy radicals to form organic peroxides. Two radicals are taken out.

The relative fraction of nitrate that exists in the particle phase (as opposed to vapor phase nitric acid or ammonium nitrate) depends in turn upon the relative concentration of acid sulfate species and ammonia. In areas with high acid sulfate concentrations (e.g. the eastern U.S. in the summer), nitrate tends to occur in the vapor phase and reductions of NOx emissions could not result in a large reductions in fine particle nitrates. Where sulfate levels are much then nitrate particle levels would be higher.

D.2 What this means for NOx Emissions and Sulfate

In urban areas with relatively high NOx emissions radical formation and propagation is inhibited. If NOx emissions are reduced by small to moderate amounts, O_3 and OH will increase. Note, the response for average O_3 can be different than the response for peak O_3. If SO_2 is available, then where the OH increases, an increase in the amount of SO_2 will be oxidized to SO_4 in the gas phase. This produces a "nonlinear" response in SO_4 (increase) to a reduction in NOx.

In rural areas with relatively models NOx levels, O_3 and OH will decrease when NOx is reduced. Percentage-wise, the decrease in O_3 and OH will less than NOx and NO_2. The ratio of OH to NO_2 will therefore increase and more of the OH budget will terminate as H_2O_2. This may or may not lead to an increase in H_2O_2. In the RADM simulations there was an increase in H_2O_2 in certain areas, especially over Ohio and western Pennsylvania. If there is excess SO_2, then where H_2O_2 increases, in increased amount of SO_2 will be converted to SO_4 in the aqueous phase. This produces a "nonlinear" response in SO_4. The larger and more pervasive source of the nonlinearity in these model results seems to be the change in H_2O_2.

The projected relative abundance of sulfate vs. nitrate particles in future years depends upon assumptions about the effectiveness of acid rain and as yet undecided strategies to implement regional haze and fine particle standards. Under the scenarios examined for this RIA, the sulfate levels were high enough to limit the amount of nitrate aerosol reduction that would accompany a regional NOx reduction. If, however, future strategies further reduced SOx emissions, the expected reductions in fine particles from NOx reductions would be decidedly larger, and more linear. Because of the uncertainties in the atmospheric chemistry for these future years, the RIA relies on modeling tools that estimate both linear and non-linear responses for PM reductions.

D.3 Reference

Dennis, R.L. Memorandum to Scott Mathias and John Bachmann, U.S. EPA Office of Air Quality Planning and Standards from Robin Dennis, U.S. EPA, Office of Research and Development, September 17, 1998.

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16. ABSTRACT

This report contains EPA's estimates of the annual costs and benefits of the final NOx SIP call and the proposed NOx FIP and CAA section 126 petition actions. The report also contains a brief profile of potentially affected sources and potential economic impacts.

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