12.0 BENEFITS OF NAAQS AND REGIONAL HAZE

12.1 RESULTS IN BRIEF

Partial attainment of the selected particulate matter (PM) National Ambient Air Quality Standards (NAAQS) is expected to yield national annual monetized benefits (health and welfare) of approximately $19 billion to $104 billion. Partial attainment of the selected ozone NAAQS is expected to yield national annual monetized benefits of approximately $0.4 billion to $2.1 billion. In addition, the benefits associated with the proposed regional haze (RH) rule are estimated to be either, zero, on the assumption that no controls beyond those needed for the NAAQS are imposed, a range of $1.3 to $3.2 billion, if all areas adopted a target of 1 deciview in 15 years, or, $1.7 to $5.7 billion for 1 deciview in 10 years. To the extent that these estimates fail to quantify many benefit categories, such as damage to ecosystems, damage to vegetation in national parks, damage to ornamental plants, damage to materials (e.g., consumer cleaning cost savings), and acid sulfate deposition, these understate actual benefits. The health and welfare benefits categories examined in this analysis and the methodology used to estimate the monetized benefits are presented below. Estimates of full attainment, though less certain than estimates for partial attainment, include a plausible range of benefits of $20 to $110 billion for $PM_{2.5}$ and a plausible range of benefits for 0.08 4th max of $1.5 to $8.5 billion.

12.2 INTRODUCTION

This chapter presents the benefits methodology and results for the PM and ozone NAAQS and a proposed RH rule. In addition, this chapter also presents the methodology and results associated with visibility improvements due to a proposed RH rule. The analysis estimates the potential human health and welfare (all benefits categories except human health) benefits associated with the PM, ozone, and RH rules. The emissions and air quality changes presented in Chapters 6, 7, and 8 are used as inputs to this benefits analysis. The following sections in this chapter include:

- The economic concept of benefits;
- The methodology for estimating post-control air quality changes;
- The methodology for estimating human health effects and the economic value associated with those effects;
- The methodology for estimating welfare effects and the economic value associated with those effects, where feasible;
- The health and welfare benefits associated with alternative PM, ozone, and RH rules;
- A discussion of potential benefit categories that are not quantifiable due to data limitations;
- A list of analytical uncertainties, limitations, and biases;

12.3 UPDATES AND REFINEMENTS

The methodology for estimating health and welfare benefits associated with the PM and ozone NAAQS builds upon previous work conducted for the December 1996 PM and ozone draft regulatory impact analyses (RIAs). This analysis retains the majority of the concentration-response relationships used in the previous RIAs. However, a number of prominent revisions to the previous draft RIAs are made. Major updates and refinements include:

- Expansion of the plausible range of benefits by attempting to quantify several areas of uncertainty that were discussed qualitatively in the preamble and RIA to the proposed rules, through the adoption of a range of plausible assumptions for several key parameters in the analysis;
- Refined estimates of the high end of the plausible range of ozone-induced mortality through a meta-analysis of recently published studies;
- Consideration of PM-related benefits attributable to emission reductions associated with control strategies implemented to meet ozone NAAQS alternatives. These benefits are referred to as ancillary PM benefits;
- The estimation of ozone-related benefits in counties outside of defined ozone nonattainment areas;

- The concept of downwind transport areas is incorporated into the post-control ozone air quality;
- Refined estimates of willingness-to-pay values for benefits categories such as chronic bronchitis and visibility;
- Incorporation of a life-years extended approach to estimate and value premature PM mortality;
- Updated economic information for the agricultural models;
- The estimation of additional benefits categories such as: reduced nitrogen deposition in sensitive estuaries, toxics reductions attributable to ozone controls, commercial forest protection in the western U.S., and visibility improvements in national parks;
- A sensitivity analysis on the air quality rollback procedure employed to simulate post-control ozone air quality;
- The application of the PM source-receptor matrix to post-control emissions on a nation-wide basis (rather than modeling region basis) to estimate PM post-control air quality. This step accounts for pollutant transport between 6 PM modeling regions.

12.4 OVERVIEW OF THE BENEFITS ANALYSIS METHODOLOGY

12.4.1 Introduction

The Clean Air Act requires EPA to set NAAQS and to regulate regional haze in order to provide benefits to society by enhancing (improving and protecting) human health and welfare. This chapter provides information on the types and levels of social benefits anticipated from the proposed rulemaking. This information includes: (1) background information on benefits assessment, describing benefits categories and issues in benefits estimation; (2) qualitative descriptions of the types of benefits associated with alternative standards; (3) quantitative estimates of benefits categories for which concentration-response information is available; and (4) monetized estimates of benefits categories for which economic valuation data are available.

12.4.2 Benefits Categories Applicable to the Regulation

To conduct a benefits analysis, the types or categories of benefits that apply need to be defined. Figure 12.1 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 his or her own exposure to an environmental risk. Use benefits categories can embody both direct and indirect uses of affected ambient air. The direct use category embraces both consumptive and nonconsumptive activities. In most applications to air pollution scenarios, the most prominent use benefits categories 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. Improved environmental quality can be valued by individuals apart from any past, present, or anticipated future use of the resource in question. Such nonuse values may be of a highly significant magnitude; however, the benefit value to assign to these motivations 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, nonuse values must be ascertained through indirect methods, such as asking survey respondents to reveal their values.

Non-use values may be related to the desire to know 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

Figure 12.1 Examples of Potential Benefits of Air Quality Improvements

USE BENEFITS	EXAMPLES
Direct	*Human Health Risk Reductions (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., an individual wanting to protect a forest even if he knows that he will never use the forest) *Ecological Benefits

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 the ecological benefits of protecting areas known as wetlands because they play a crucial role in our ecological system, even if the wetlands themselves are not directly used by humans.

The majority of health and welfare benefits categories presented in this analysis can be classified as direct use benefits. These benefits are discussed in greater detail compared to other benefits categories presented in Figure 12.1 because more scientific and economic information has been gathered for the direct use benefits category. For example, scientific studies have been conducted to discern the relationship between ozone exposure and subsequent effects on specific health risks and agricultural commodities. In addition, economic valuation of these benefits can be accomplished because a market exists for some categories (making it possible to collect supply, demand, and price information) or contingent valuation studies have been conducted for categories that people are familiar with (such as willingness-to-pay surveys for non-market commodities).

Detailed scientific and economic information is not as readily available for the remainder of the benefits categories listed in Figure 12.1. 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. A homeowner living in the affected area with ornamental plants in his yard is expected to benefit from the reduced damage to his plants, with his 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., concentration-response relationships for urban ornamentals and values associated with specific types of injuries and mitigation) prevent quantification of this benefits category.

Another problem related to lack of information is the difficulty in identifying <u>all</u> benefits categories that might result from environmental regulation and in valuing 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. The nature of this problem is due to the non-market characteristic of many benefits categories. Since many pollution effects (e.g., adverse health or agricultural 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 discussion.

The inability to quantify the majority of the benefits categories listed in Figure 12.1 as well as the possible omission of relevant environmental benefits categories may lead the quantified benefits presented in this report to be underestimated relative to total benefits. It is not possible to estimate the magnitude of this underestimate.

Tables 12.1 and 12.2 present the quantifiable and unquantifiable human health and welfare effects associated with exposure to PM, ozone, and RH. Note that since the pollutants contributing to RH formation are similar to those contributing to particulate formation, the health and welfare categories associated with PM are also associated with RH.

Table 12.1 PM and RH Benefits Categories

	PM Health and Welfare Benefit Categories	
	Unquantified Benefit Categories	**Quantified Benefit Categories (incidences reduced and/or dollars)**
Health Categories	Changes in pulmonary function Morphological changes Altered host defense mechanisms Cancer Other chronic respiratory disease Infant Mortality Mercury Emission Reductions	Mortality (acute and long-term) Hospital admissions for: all respiratory illnesses congestive heart failure ischemic heart disease Acute and chronic bronchitis Lower, upper, and acute respiratory symptoms Respiratory activity days Minor respiratory activity days Shortness of breath Moderate or worse asthma Work loss days
Welfare Categories	Materials damage (other than consumer cleaning cost savings) Damage to ecosystems (e.g., acid sulfate deposition) Nitrates in drinking water Brown Clouds	Consumer Cleaning Cost Savings Visibility Nitrogen deposition in estuarine and coastal waters

* There may be orders of magnitude differences in the size of these benefit categories.

Table 12.2 Ozone Benefits Categories

	Ozone Health and Welfare Benefit Categories	
	Unquantified Health Benefit Categories	**Quantified Benefit Categories (in terms of incidences reduced or dollars)**
Health Categories	Airway responsiveness Pulmonary inflammation Increased susceptibility to respiratory infection Acute inflammation and respiratory cell damage Chronic respiratory damage/ Premature aging of lungs	Coughs Pain upon deep inhalation Mortality Hospital admissions for: all respiratory illnesses pneumonia chronic obstructive pulmonary disease (COPD) Acute respiratory symptoms Restricted activity days Lower respiratory symptoms Self-reported asthma attacks Cancer from air toxics Change in lung function
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) 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	Commodity crops Fruit and vegetable crops Commercial forests Consumer Cleaning Cost Savings Visibility Nitrogen deposition in estuarine and coastal waters Worker productivity

* See footnote to Table 12.1 on page 12-8.

12.4.3 Economic Benefits

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 terms 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, the other methods of examining changes in relevant markets 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.

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 above, it may not be possible to quantify the value of all benefits resulting from environmental quality improvements.

12.4.4 Linking the Regulation to Beneficial Outcomes

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 12.2, which illustrates the causality for air quality related benefits, these relationships span the spectrum of: (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 biologic/ecologic responses in the environment, and (4) human responses and values associated with these changes.

The first two steps of Figure 12.2 reflect the institutional and technical aspects of implementing the regulation (the improved process changes or pollutant abatement). The benefits analyses presented in this document begin at the step of estimating reductions in ambient ozone concentrations. 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 either a source-receptor matrix (see chapter 4) or an air quality rollback procedure given the predicted 2010 baseline air quality. Chapter 4 of this report presents the methodology used to estimate baseline ambient PM and ozone air quality in the year 2010.

This RIA presents two scenarios for analyzing reductions in ambient PM and ozone air quality. The first, referred to as the partial attainment scenario, is intended to reflect residual nonattainment information as presented in the partial attainment cost analysis. For each area identified as not having sufficient control measures to allow it to attain a particular standard, the post-control air quality estimated for each area is intended to reflect the degree of residual nonattainment for that area. The health and welfare benefits estimated for this partial attainment scenario represent the identifiable benefits expected to result from the application of control measures as identified in the partial attainment cost analysis. The second scenario, referred to as the full attainment scenario, relies on the assumption that all areas will be able to attain any PM

Figure 12.2 Example Methodology of a Benefits Analysis

Specified PM/Ozone/RH NAAQS Alternative

↓

Expected Changes in Production Processes and/or Treatment

↓

Reductions in Pollutant Emissions

↓

Reductions in Ambient PM/Ozone Air Quality

↙ ↘

Change in Plant Damage, Crop Yields, and Other Welfare Effects

↓

Change in Supply and Value of Crops, Vegetables, and other welfare effects

Change in Adverse Human Health Symptoms and Risk

↓

Change in Value of Reduced Adverse Human Health Symptoms and Risk

or ozone NAAQS being evaluated. The health and welfare benefits presented under this scenario represent the identifiable benefits that should accrue if all areas in the United States could comply with the standard being analyzed. Note that the benefits presented for the full attainment scenario will always exceed the benefits presented for the partial attainment scenario since the partial attainment scenario accounts for residual nonattainment. Chapter 4 presents a discussion of the models used to estimate baseline PM and ozone air quality.

Other information necessary for the analysis are the physical and chemical parameters and the consequent improvement in the environment (e.g., concentration-response data). Finally, the analysis reaches the stage at which anthropocentric benefits concepts begin to apply, such as reductions in human health risk and improvements in crop yields. These final steps reflect the focal point of the benefits analyses, and are defined by the benefits categories described above. Below, relevant benefits categories are described qualitatively, and where possible, quantitatively.

12.4.5 Plausible Range of Monetized Benefits

As discussed throughout this RIA, there are many sources of uncertainty in estimating both the costs and the benefits of complex regulatory programs such as those that will be required to implement the ozone and PM NAAQS. These include uncertainties about the effects of emissions reductions on air quality, uncertainties about the effects of changes in air quality on health and welfare endpoints of concern, and uncertainties about the economic valuation of these endpoints. For this reason, this RIA has adopted the approach of presenting a "plausible range" of monetized benefits that reflects these uncertainties by selecting alternative values for each of several key assumptions. Taken together, these alternative sets of assumptions define a "high end" and a "low end" estimate for the benefits that have been monetized in this analysis.

In choosing alternative assumptions, EPA has attempted to be responsive to the many comments received on the RIAs that accompanied the proposed rules. As a result, the ranges of benefits presented here are substantially wider than the ranges that were presented in the RIAs for the proposed rules. It should be emphasized, however, 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, 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. The analysis attempts to present a plausible range of monetized benefits for the categorizes that have been analyzed. It should also be noted, as discussed in greater detail above, that a number of benefits categories have not been monetized, because of both conceptual and technical difficulties in doing so. These benefits are in addition to the plausible range of monetized benefits considered here.

The uncertainties that have been incorporated into the analysis are noted throughout the discussion of the methodology that follows. However, a few key assumptions, which have a substantial impact on the analysis and which together account for most of the differences between the high and low end estimates are note here.

For PM, one significant source of uncertainty is the possible existence of a threshold concentration below which no adverse health effects occur. As noted in the preamble to the rule, the epidemiological evidence for effects above the level chosen for the annual standard is substantially stronger than the evidence for effects below that level. As noted in the preamble, although the possibility of effects at lower annual concentrations cannot be excluded, the evidence for that possibility is highly uncertain and the likelihood of significant health risk, if any, becomes smaller as concentrations approach background. Consequently, in constructing the high and low end benefits estimates, the following alternative assumptions were used. The high end estimate assumes that health benefits from reductions in $PM_{2.5}$ occur all the way down to background levels for chronic bronchitis and 12 $\mu g/m^3$ mean for long-term mortality. The low end estimate assumes that health benefits occur from $PM_{2.5}$ reductions only down to the level of the standard, or 15 $\mu g/m^3$ for all endpoints. Based on the risk assessment for mortality, approximately 60 percent of mortalities are estimated to occur above 15 $\mu g/m^3$; that adjustment is applied to all PM health benefits for the low end estimate.

There is also substantial uncertainty about the extent of reduced mortality that may be associated with ozone reductions. A number of studies documenting a possible relationship between ozone and premature mortality are newly available, but these studies were not available at the time of the CASAC review of the Criteria Document and Staff Paper, and thus were not reviewed by CASAC and were not used in establishing the basis for the new 8-hour standard. The high end estimate for ozone benefits is based on a meta analysis (discussed in more detail below) of nine of the more complete of these recent epidemiological studies, while the low end estimate assumes no mortality benefits from ozone reductions.

Furthermore, in the RIAs for the proposed rules, benefits that result from reductions in fine particles were attributed only to the PM standard, and benefits that result from reductions in ozone were attributed only to the ozone standard. In fact, however, NOx is a major precursor of both pollutants, so that control measures that reduce NOx emissions may lead to significant reductions in both ozone and fine partculates. It follows that even in the absence of an ozone standard, there would be some ozone benefits from a fine PM standard, and conversely, there would be some PM benefits from an ozone standard even in the absence of a $PM_{2.5}$ standard. There is thus some ambiguity about where to assign benefits that result from control measures that contribute to the attainment of both standards. To account for this ambiguity, the high end benefits estimate for ozone attributes to the ozone standard ("ancillary" PM benefits), while the low end estimate for ozone does not include these ancillary benefits.

Finally, there is substantial disagreement about the appropriate method for valuing reductions in risk of premature mortality. The RIAs for the proposed rule used a value per statistical life saved (VSL) of $4.8 million. This represents an intermediate value from a variety of estimates that appear in the economics literature. It is a value that EPA has frequently used in RIAs for other rules. However, it has been pointed out that a substantial fraction of the premature deaths "avoided" by reductions in fine PM may represent life shortening by as little as a few days or weeks among individuals already suffering from severe respiratory or cardiopulmonary disease. Further, the average age of individuals who die from causes associated with fine PM is significantly higher, and the age specific life expectancy correspondingly lower, than the average age and life-expectancy of individuals used in the studies from which estimates of VSL were derived.

An alternative approach to valuing reductions in premature mortality that addresses these concerns is to estimate total life years extended, rather than premature deaths avoided, and multiply the result by the value of a statistical life-year extended (VSLY). This approach attempts to estimate not only how many premature deaths are avoided, but by how long these deaths are postponed. It is consistent with, but less refined than, the approach recommended in 1993 by the U.S. Public Health Service Panel on Cost-Effectiveness in Health and Medicine, which is the incorporation of morbidity and mortality consequences into a single measure quality adjusted life years (Haddix, et. al., 1996). This alternative approach then assigns a value to each life-year extended, rather than to each death postponed. In this analysis, the high-end estimate for mortality benefits used the VSL approach, with a value of $4.8 million per statistical life saved, while the low-end estimate uses the VSLY approach. While there is currently little quantitative evidence regarding the extent of life shortening reflected in the short term mortality studies, concerns have been raised that a significant fraction of this mortality may reflect life shortening by only a few days or weeks. In contrast, the CAA Section 812 Study notes that the life expectancy of 65-74 year olds, among whom much of the PM-related mortality occurs, is 14 years. This figure does not account for the possibility that much of the premature mortality may occur among individuals who are already suffering from serious respiratory or cardiopulmonary disease. Consequently, in constructing the low-end estimate, the assumption is made that two-thirds of the PM-related mortality reductions estimated from short-term studies represent life shortening of no more than a few weeks, while one-third represents life shortening of 14 years. The resulting estimate of life years extended monetizes the life years lost estimate value of $120,000 per year. This represents the midpoint value from the range of published estimates (Tolley et. al., 1994, p.313).

12.4.6 Comparison of RIA to NAAQS Risk Assessment

The process of proposing and promulgating a revised NAAQS requires the Agency to conduct a series of analyses, two of which examine the health and welfare implications of revising the NAAQS. The first of these analyses is the risk assessment and exposure analyses, summarized in the PM and ozone Staff Papers and supplemental analyses, which are part of the scientific rationale for these health-based standards. (U.S. EPA, 1996c, 1996d) The second is the benefits analysis included in this RIA. In general, this RIA adopts the basic methods employed in the exposure analyses and risk assessment but attempts to expand the scope of the exposure analyses and risk assessment in an effort to identify and quantify all potential benefits categories.

To the extent possible, this health benefits analysis is methodologically consistent with analyses conducted for the PM and Ozone Staff Papers; however, this RIA's health benefits analysis differs from the exposure analyses and risk assessment in five ways.

1. This updated benefits analysis includes a number of health and welfare endpoints that were not included in the risk assessments. The two analyses are different because they serve different purposes: the risk assessment is used to provide a scientific basis for revising the current NAAQS while the purpose of this benefits analysis is to identify <u>all potential</u> health and environmental benefits associated with alternative NAAQS levels. Therefore, this benefits analysis must provide discussions or estimates of all health and environmental effects believed to be associated with exposure to ozone and PM. In addition to expanding the types of endpoints that are included in the analysis, this analysis estimates PM-related benefits attributable to emission reductions associated with control strategies implemented to meet the ozone NAAQS alternatives. These benefits are referred to as ancillary PM benefits associated with the ozone NAAQS. All health and welfare endpoints that are listed for the PM benefits analysis are also estimated for the ozone NAAQS analysis if ozone control strategies reduce NOx emissions, which also have an effect on PM air quality. The ancillary PM benefits occur mostly in areas that

have PM concentrations below the 15 µg/m^3 threshold assumed in the low-end estimate. Areas that have concentrations above 15 µg/m^3 would be out of attainment for $PM_{2.5}$, and it is not clear how to "divide up" the PM benefits between the ozone and PM standards for these areas. Therefore, the PM ancillary benefits are not included in the low-end estimate.

2. This benefits analysis expands the geographical scope of the exposure analyses and risk assessment. The PM and ozone benefits are estimated for the continental U.S. (referred to as a national analysis) as opposed to the risk assessment's limited number of 2 cities for PM and 9 urban areas for ozone. In addition, the PM and ozone benefits are estimated for a full calendar year as opposed to the ozone risk assessments limitation to the ozone season (the PM risk assessment however, was also estimated for a full year). The scope of the benefits analysis is expanded because the NAAQS are nationally applicable rules and control strategies implemented to reduce emissions are typically operated all year.

3. The exposure analyses and risk assessments use population and air quality data from relatively current years (1990 to 1993) to estimate risk reductions. In contrast, this benefits analysis estimates health and welfare effects for projected populations and ambient PM and ozone reductions in the year 2010. The year 2010 is an appropriate time period of analysis for this RIA because the purpose of this analysis is to identify potential benefits and costs associated with the standards when they are implemented. The year 2010 is believed to be a representative year for the purposes of this RIA.

4. The risk and exposure analyses employs a proportional air quality rollback procedure for both the PM and ozone NAAQS (with alternative rollback procedures as sensitivity analyses for ozone). This benefits analysis employs the same proportional air quality rollback procedure for the PM full attainment analysis (an air quality model is used to estimate partial attainment PM concentrations) but applies a hybrid version of the proportional rollback procedure, called quadratic rollback, to simulate post-control ozone

air quality. The quadratic procedure is used for the ozone analysis because the scope of the benefits analysis, especially the time over which benefits are calculated (full year rather than ozone season only), is more broad compared to the ozone risk and exposure assessment. In response to public comments on the ozone exposure analyses and risk assessment, EPA has conducted sensitivity analyses using alternative air quality rollback procedures; including the quadratic rollback employed in this RIA. EPA believes the quadratic rollback procedure generally is more reflective of how ozone levels decreased for many geographic areas and thus, is more suitable for use in a national analysis for a full year. See section 12.6 for a more detailed explanation of the characteristics of the rollback procedures.

5. A significant difference between this benefits analysis and the PM and ozone risk and exposure assessment is the inclusion of the ozone-induced mortality category in the high-end estimate for this analysis. The inclusion of this category creates a significant difference in the benefits results because of the number of avoided mortality cases predicted in new epidemiological assessments and the monetary estimate used to value these avoided cases. A short discussion of the ozone mortality issue is presented here due to this significant difference between this benefits analysis and the risk and exposure assessment.

A number of community epidemiology studies have suggested a possible association of ozone with mortality. The ozone criteria document review of the literature concluded that although an association between high ozone levels and mortality has been suggested, the strength of any such association remained unclear (U.S. EPA, 1996a). However, although early studies of this issue are flawed (e.g., due to poor control for confounders), a significant number of new studies (21 peer-reviewed studies, 12 since CASAC closure) have been published recently that provides more support for an association between ozone exposure and mortality. Although this benefits analysis uses data from these new studies to quantitatively estimate the relationship between ozone exposure and mortality for the high-end estimate, it is important to distinguish the role of this benefits analysis in comparison to the NAAQS risk and exposure assessment.

Results generated by the NAAQS exposure analyses and risk assessment are directly used to determine the appropriate level at which to set a criteria pollutant standard such that public health is protected with "an adequate margin of safety." The exposure analyses and risk assessment use only studies that have been reviewed by the Clean Air Science Advisory Committee (CASAC). The purpose of this benefits analysis is to identify and quantify, to the extent possible, all potential benefits categories that might result from implementation of the revised standards.

The additional ozone mortality studies provide increasing evidence of associations between ozone exposure and daily mortality. While many of these studies show an association between ozone exposure and mortality, studies over longer time periods, which collect and use more data, show stronger statistical significance compared to studies conducted over relatively shorter time frames. See the Benefits Technical Support Document (TSD) (U.S. EPA, 1997a) for a more complete description of the ozone mortality meta-analysis. Because significant uncertainty still exists in the estimation of ozone-induced mortality, this category of benefits is included in the high-end estimate but excluded from the low-end estimate.

12.5 SCOPE OF ANALYSIS

The goal of this analysis is to estimate national-level benefits associated with the revised PM and ozone standards as well as the regional haze program for the year 2010. As was previously explained in this RIA, baseline PM air quality data are reported in two ways: an annual distribution and a daily distribution. Baseline hourly ozone air quality data are generated for the entire year in 2010. Both PM and ozone air quality are projected at their respective existing monitor sites. The monitor-site air quality data are then used to interpolate PM and ozone air quality for all unmonitored counties in the continental U.S. Post-control air quality is then estimated (using either the source-receptor matrix or the air quality rollback procedure) for each of the baseline air quality values. The air quality rollback procedure is applied to the appropriate baseline air quality values for the entire year.

This benefits chapter presents national-level summary results associated with the NAAQS and RH alternatives analyzed in this report. However, readers interested in smaller units of aggregation (e.g., each of the six PM regions or each of the ozone nonattainment areas) can refer to the Benefits TSD.

12.6 ESTIMATION OF POST-CONTROL AIR QUALITY

12.6.1 Introduction

The discussion accompanying Figure 12.2 explains that the starting point for this benefits analysis is the estimation of reductions in ambient concentrations of PM and Ozone. Previous chapters in this analysis have provided information on the development of baseline emissions and air quality as well as the estimation of emission reductions and costs associated with implementation of the various NAAQS alternatives. This chapter continues the analysis by converting the estimated emission reductions into decreased ambient PM and ozone concentrations. The air quality change is defined by two scenarios: (1) Partial Attainment (to reflect air quality improvement expected given the adoption, where needed, of reasonably cost-effective emissions controls for which adequate cost-effectiveness data exist, and (2) Full Attainment (to reflect the potential benefits if all areas are able to meet the standards).

12.6.2 Derivation of Annual Distribution of Daily PM Concentrations

As described in Chapter 4, baseline PM air quality predicted by the source-receptor matrix is used as input to the benefits analysis. Because the annual distribution of daily PM concentrations cannot be predicted by the model, they must be derived from other predicted information. A reasonable functional form for county-specific air quality distributions can be assumed, based on an examination of PM distributions in recent years for which actual data exist. Once a functional form is chosen, all that is unknown about a given county-specific distribution are the values of its parameters. The model-predicted statistics, the annual mean and the 98th or 99th percentile daily maximum, can then be used to estimate these parameters, for each county-specific distribution, completing the estimate of the county-specific distribution of daily PM concentrations in the year 2010. For the baseline PM_{10} alternative, the fourth highest daily maximum value is used. For the selected PM_{10} alternative, the 99th percentile daily maximum value is used. For the $PM_{2.5}$ alternatives, the 3-year average 98th percentile daily maximum value is used. Daily PM concentrations are then generated from this estimated distribution.

To determine the most reasonable annual distributional form for the daily PM concentrations in each county in the United States for the year 2010, PM data for recent years in each of four locations (Philadelphia, PA; St. Louis, MO; Provo, UT; and El Paso, TX) were fit to a number of distributions (including, but not limited to, the lognormal, the beta and the gamma distributions). The gamma distribution was chosen because it generally provided the best fit. The above procedure was carried out for each county in the national analysis, generating 365 daily PM_{10} and 365 daily $PM_{2.5}$ concentrations for each county in the analysis. The procedure used to estimate the two parameters of the gamma distribution and to then generate a year's worth of daily PM concentrations from the fully specified distribution is described in detail in the Benefits TSD (U.S. EPA, 1997a).

12.6.3 Partial Attainment Air Quality Estimation

The partial attainment benefits scenario is assessed to account for the presence of residual nonattainment for both PM and ozone (as described in Chapters 6,7, and 8). Under the partial attainment scenario, the goal is to approximate post-control air quality related to emission reductions achieved by the specific control measures identified in the cost analysis. The reader should keep in mind that even under this partial attainment scenario, there are some areas that the cost analysis estimates will be able to fully attain either the PM and/or the ozone standards. The difference between the full and partial attainment scenarios is that for the partial attainment scenario, under each alternative NAAQS evaluated, a number of areas are identified as residual nonattainment areas, where insufficient control measures are identified to simulate full attainment. Given that the goal of the partial attainment benefits scenario is to link projected emission reductions, costs, and the resulting air quality improvements, the benefits results presented under the partial attainment scenario should be viewed as the results most comparable to the partial attainment cost estimates presented in Chapters 6, 7, and 8.

As described in chapter 4 and chapter 6, the source-receptor matrix and PM cost optimization model are is used to estimate least-cost reductions of primary PM and PM precursors to attain alternative PM standards. Ambient PM concentrations are expected to be affected by both the type of emissions reduced [i.e., nitrogen oxides (NOx), sulfur oxides (SOx), volatile organic compounds (VOC), PM_{10}, $PM_{2.5}$, or ammonia] and the location of the emission reductions. Note that since NOx and VOC are precursor emissions for both PM <u>and</u> ozone, the source-receptor matrix can be used to estimate ambient particulate reductions expected to result from controls imposed under both the PM and the ozone NAAQS. Once control measures are identified in the control strategy/cost analysis, post-control emissions are input to the source-receptor model to predict nationwide post-control PM air quality. This step is conducted to account for pollutant transport between the 6 modeling regions delineated in chapter 6.

The estimation of ambient ozone concentration reductions is more problematic compared to the PM procedure described above. Lack of a <u>national</u> ozone air chemistry model precludes creating a direct link between the imposition of pollution control strategies (as identified in the cost analysis) and the resulting ambient ozone concentration. Rather, this analysis relies on an air quality adjustment procedure (referred to as quadratic rollback) to reduce hourly baseline ozone concentrations. This approach uses a quadratic formula such that relatively higher ozone concentrations get reduced by a greater percentage than relatively lower ozone concentrations . The partial attainment air quality rollback procedure is intended to reflect the degree of nonattainment for each residual nonattainment area.

For each ozone standard analyzed, the cost analysis attempts to identify control strategies that will enable each nonattainment area to achieve its targeted emission reductions. Two outcomes are possible within the analysis: (1) emission reduction targets are achieved or (2) controls likely to be imposed do not fully achieve the emission reduction targets by 2010. Starting with the first example, if an area initially classified as nonattainment is projected to be able to meet its targeted emission reductions, that area is classified as an initial nonattainment area that, with the implementation of additional control strategies, will be able to attain the standard. Under this example, the design value for the nonattainment area (i.e., the recorded monitor value that causes the area to be classified as a nonattainment areas) is reduced by X percent to comply with the standard. All other monitor values within the nonattainment area are also reduced by some smaller percentage compared to X, as determined by the quadratic equation. Also, under this attainment case, the rounding convention of .005 parts per million (ppm) is employed in the air quality rollback procedure. For example, if the standard under evaluation is an 8-hour, .08 ppm standard, the quadratic rollback procedure is employed to reduce the design value ozone concentration to a value of .084 ppm.

The partial attainment scenario also contains a number of areas that belong in the second category. Since the area cannot be deemed to be able to attain the standard within the study period, the air quality rollback procedure must be modified to reflect the presence of residual nonattainment. Relevant information that is known for each nonattainment area includes: (1) the design value causing the area to be classified as nonattainment; (2) the targeted VOC and NOx emission reductions believed to be necessary to enable the area to comply with the standard being analyzed; and (3) the total VOC and NOx emission reductions thought to be possible given identifiable control measures. Using the above information along with an assumption of linearity between emission reductions and ambient ozone concentrations, it is possible to employ the quadratic rollback procedure to approximate partial attainment air quality. Targeted VOC and NOx emission reductions are summed. Achieved NOx and VOC emission reductions are treated equally. A ratio of total achieved to targeted emission reductions is then calculated. This ratio provides the degree of partial attainment that is then applied to the air quality rollback of the design value to meet a particular ozone standard. For example, if an area is estimated to be able to only achieve 50 percent of its targeted emission reductions, then the 50 percent value is used to reduce the design value to only 50 percent towards attainment of the standard (where 100 percent implies full attainment because the emission reductions targets are fully met). Downwind transport areas as described in chapter 4 are also rolled back the same amount as their upwind nonattainment areas. Once these partial attainment rollbacks are complete, the centroid model (see section 4.5.4) is re-run to provide nationwide post-control ozone air quality.

12.6.4 Full Attainment Air Quality Estimation

Because full attainment of the alternative NAAQS nationwide will require use of new technologies whose costs cannot yet be assessed accurately, full attainment of each alternative is simulated by changing the distribution of daily PM or ozone concentrations. The methods described below for adjusting baseline air quality to simulate full attainment apply to both the PM and ozone benefits analyses. The procedure used to adjust both the PM and ozone air quality is referred to as the air quality rollback procedure.

In the absence of historical $PM_{2.5}$ air quality monitoring data, it may be reasonable to simulate full attainment of the PM alternatives by employing a proportional rollback procedure (i.e., by decreasing the appropriate baseline PM and ozone concentrations on all days by the same percentage). An assessment of the plausibility of estimating full attainment air quality by using a proportional (also referred to as linear) rollback procedure is presented in the PM risk assessment (Johnson, 1997). The assessment examines historic changes in $PM_{2.5}$ and concludes that the proportional rollback procedure is a good approximation for the historical decrease in PM levels.

As with the ozone partial attainment scenario, the quadratic air quality rollback procedure is employed to simulate full attainment of the ozone alternatives because historical monitoring data indicates that lower ozone concentrations may decrease by a smaller proportion compared to higher ozone concentrations when control strategies are implemented.

For the PM NAAQS, the full attainment benefits analysis begins where the partial attainment analysis ended. Under the PM full attainment benefits analysis, the proportional rollback procedure is employed to simulate full attainment in the residual nonattainment areas (i.e., by decreasing the appropriate baseline PM concentrations on all days by the same percentage). The PM percent reduction is determined by the controlling standard. For example, suppose both an annual and a daily PM 2.5 standard are proposed. Suppose P_a is the percent reduction required to attain the annual standard (i.e., the percent reduction of daily PM necessary to get the annual average at the monitor with the highest annual average down to the standard). Suppose P_d is the percent reduction required to attain the daily standard with one exceedance (i.e., the percent reduction of daily PM necessary to get the second-highest monitor-day down to the daily standard). If P_d is greater than P_a, then all daily average PM concentrations are reduced by P_d percent. If P_a is greater than P_d, then all daily average PM concentrations are reduced by P_a percent. A rounding convention is also employed in the rollback procedure. Using the proposed $PM_{2.5}$ standard of 15/50 $\mu g/m^3$ as an example, the annual value is reduced to a value of 15.04 $\mu g/m^3$ while the daily value would be reduced to a value of 50.4 $\mu g/m^3$.

For ozone, the process is slightly simpler since there is only one standard to attain at any given time. For example, the design value for a nonattainment area (i.e., the recorded monitor value that causes the area to be classified as a nonattainment area) is reduced by X percent to comply with the standard. Accordingly, the quadratic air quality rollback procedure employed in the ozone partial attainment scenario is also employed in the full attainment scenario. The only difference between the two scenarios is that the ozone full attainment scenario always reduces each nonattainment area’s design value to exactly the level of the evaluated standard. The full attainment scenario adheres to the same rounding convention of .005 ppm.

12.6.5 Air Quality Background Levels and Benefits Thresholds

The term background air quality refers to pollution caused by natural sources (as opposed to those caused by anthropogenic sources) and is defined as the distribution of air quality that would be observed in the U.S. in the absence of anthropogenic emissions of PM, VOC, NOx, and SOx in North America. For example, volcanoes emit sulfate precursors and trees emit VOC (i.e., terpenes), which each contribute to PM and ozone formation, respectively.

The health benefits estimation for PM uses two alternative assumptions about benefits from reductions below the level of the standard. The high-end estimate assumes benefits from fine particulate reductions down to 12 $\mu g/m^3$ mean for mortality due to long-term exposure and reductions down to background levels for chronic bronchitis. The PM Staff Paper provides background values for PM_{10} versus $PM_{2.5}$ and west versus east (U.S. EPA, 1996d). Midpoint background values for PM_{10} are estimated at 6 $\mu g/m^3$ for the west and 8 $\mu g/m^3$ for the east. Midpoint background values for $PM_{2.5}$ are estimated at 2.5 $\mu g/m^3$ for the west and 3.5 $\mu g/m^3$ for the east. This analysis uses background PM concentrations for benefits models that do not report a lowest-observed PM concentration or if the reported lowest-observed concentration is below background. For models that report a lowest-observed concentration (the lowest PM concentration at which the concentration-response function is supported) at a higher value than background levels, benefits estimates are only calculated for air quality changes down to the lowest observable level. For example, the Pope et al. study reports a lowest observed annual median $PM_{2.5}$ level as 9 $\mu g/m^3$. Therefore, the concentration-response function is relied upon only down to the 9 $\mu g/m^3$ annual median concentration. The short-term PM-mortality studies generally do not report lowest observed concentrations and are therefore, estimated down to background concentrations. Similarly, most PM-mortality studies do not report lowest-observed levels and are also estimated down to background concentrations. As discussed in the preamble to the rule, benefits from reductions below the standard are significantly more uncertain than those from reductions above the level of the standard. The low-end estimate thus uses a threshold concentration of 15 $\mu g/m^3$, below which further reductions are not assumed to yield additional health benefits. This has the effect of reducing the incidence of estimated health benefits by about 40 percent.

A background level is also imposed on the ozone concentration-response models. A midpoint background value estimated in the ozone Staff Paper is 0.04 ppm (U.S. EPA, 1996c). This analysis accounts for background ozone concentrations by evaluating benefits models only down to the 0.04 level but not below this level. This limitation is placed on models that do not report thresholds or report thresholds below 0.04 ppm. For example, while most ozone-mortality studies report lowest observed ozone concentrations, the concentrations are uniformly lower than 0.04 ppm. Ozone concentration-response functions are therefore, estimated down to background levels. In addition, some clinical studies introduce additional thresholds which are above the assumed background level, in which case, benefits estimates are only calculated for air quality changes down to the reported threshold level.

12.6.6 Ozone Air Quality Rollback Sensitivity Analysis

As mentioned earlier when comparing this benefits analysis to the NAAQS risk and exposure assessment, a point of departure between the two analyses is the air quality rollback procedure applied to ozone data. The risk and exposure assessment applied a proportional air quality rollback procedure to ozone-season air quality values in 9 sample urban areas. In addition, the assessment also conducted several air quality rollback sensitivity analyses, comparing results using a weibull distribution as well as the quadratic rollback procedure.

As noted above, that the quadratic rollback procedure reduces non-peak ozone values (e.g., wintertime ozone values) by a smaller proportion compared to peak ozone values (e.g., ozone concentrations at design-value monitors). The quadratic rollback procedure is deemed to be appropriate for this benefits analysis because the procedure is employed to adjust baseline air quality values for a full calendar year. However, this benefits analysis also conducts a sensitivity analysis using the proportional air quality rollback procedure. In general, the use of a proportional air quality rollback procedure compared to the proportional rollback procedure yields results that are 2 times larger. See the Benefits TSD for more details (U.S. EPA, 1997a). The weibull rollback procedure is data intensive and lack of historical data on a national basis for the analysis year prevents a sensitivity analysis of the weibull rollback procedure to be conducted.

12.7 HUMAN HEALTH BENEFITS

12.7.1 Introduction

Exposure to PM, ozone, and RH can result in a variety of health and welfare effects. The relevant PM, ozone, and RH human health and welfare effects that are quantified (expressed in terms of incidences reduced) and monetized (expressed in terms of dollars) are presented in Tables 12. 1 and 12.2. Note that since the pollutants contributing to RH formation are similar to those contributing to particulate formation, the health and welfare benefits categories associated with PM are also associated with RH. Additionally, note that all health and welfare effects identified for PM and RH in Table 12.1 are also applicable in the high-end estimate to ozone reductions because ozone control strategies may also reduce particulate concentrations through the control of NOx emissions. All categories of benefits listed in Tables 12.1 and 12.2 that are monetized are also quantified. However, some quantified benefits categories are not monetized due to one of two reasons: (1) economic valuation information is not available or (2) a concern about double-counting or an overlapping of effects categories led to a decision to omit a particular benefits category from the aggregation scheme. These issues are discussed in greater detail in Appendix I of this RIA.

For benefits categories listed as unquantified, scientific data are not available for quantifying the relationship between ozone and incidences of each symptom. However, the unquantifiable health benefits categories are listed because evidence in the scientific literature creates a reasonable connection between PM and ozone exposure and these health and welfare effects categories. For example, the collective toxicologic data on chronic exposure to ozone garnered in animal exposure and human population studies provide a biologically plausible basis for considering the possibility that repeated inflammation associated with exposure to ozone over a lifetime may result in sufficient damage to respiratory tissue such that individuals later in life may experience a reduced quality of life. However, such relationships remain highly uncertain due to ambiguities in the data.

The result of having potentially significant gaps in the benefits calculations may lead to an underestimation of the monetized benefits presented in this report. The effect of this potential underestimation is to limit the conclusions that can be reached regarding the monetized benefits and net benefits estimates of each of the PM, ozone, and RH alternative standards.

12.7.2 Health Benefits Methodology

As illustrated in Figure 12.2, the next step in this benefits analysis is to estimate the change in adverse human health effects expected to result from a decrease in ambient PM and/or ozone concentrations. To accomplish this task, a series of scientific studies evaluating the relationship between PM and/or ozone exposure and human health effects are identified. Statistical techniques are employed to estimate quantitative concentration-response relationships between pollution levels and health effects.

A correction has been made from the November Draft RIA in the calculation of the reductions in long-term exposure mortality associated with attainment (or partial attainment) of alternative $PM_{2.5}$ standards. In the previous analysis, changes in long-term $PM_{2.5}$ concentrations in each county were characterized by changes in the annual *mean* concentration for the county. Changes in the incidence of long-term exposure mortality associated with changes in annual mean concentrations were estimated using the concentration-response relationship reported by Pope et al., 1995. However, it appears that Pope et al. estimated the relationship between changes in mortality incidence and changes in the *median*, rather than the *mean*, of daily average concentrations across the year (or across several years). Long-term exposure mortality incidence was re-estimated, based on changes in annual median concentrations rather than annual mean concentrations, for each scenario considered. The reductions in the estimates of monetized benefits associated with long-term exposure mortality reduction due to this correction are generally about 20 percent. The lowest observable value reported in the Pope et al. study is a 9 $\mu g/m^3$ median value. A corresponding mean value is estimated to be approximately 12 $\mu g/m^3$.

Of special interest is the mortality benefits category for both PM and ozone since this category contributes a major portion of the estimated total monetized benefits (except for the low-end estimate for ozone). As explained earlier, the PM concentration-response functions included in this analysis are generally consistent with the PM NAAQS risk and exposure assessment. The studies included in the analyses were reviewed by the CASAC and judged against a set of criteria (e.g., must be published) as detailed in the Benefits TSD (see Appendix J). Also, as explained earlier in this chapter, the relatively newer ozone mortality studies that have been published or accepted by a peer-reviewed journal, but have not yet been through the CASAC or Criteria Document review process. In the absence of this review, this analysis includes in the high-end estimate a detailed assessment of the new ozone mortality studies through a meta-analysis. A subset of 9 ozone mortality studies are chosen for this benefits analysis and are also cross-referenced to the list of PM mortality studies. See Appendix J for details on the studies and the selection criteria.

Of the 9 ozone mortality studies, only two studies providing information for PM-related mortality had not already been included in the PM analysis. One of these studies was conducted in Amsterdam while the other was conducted in Chile. It is believed that the mix of precursor and primary emissions contributing to particulate formation varies widely due to factors such as geography and human and economic activity. It is also believed that the health effects associated with PM exposure are dependent upon the chemical constituents of ambient PM concentrations. For these reasons, one of the criteria used to select studies for inclusion in the PM risk and exposure analysis (and therefore, the PM benefits analysis) is that the studies had to have been conducted in the U.S. or Canada, where the population and human and economic activity patterns are relatively similar. The use of this criterion eliminates the possibility of including data from studies conducted elsewhere, such as Europe or South America. Unlike PM, there are only two precursor emissions for ozone. Although the mix of these pollutants may vary from area to area, the difference of the mix is not believed to cause a significant difference in the type or degree of health effects believed to be associated with ozone exposure (U.S. EPA, 1996b). Therefore, although the ozone mortality meta-analysis includes new studies published since review of the Criteria Document and conducted in areas outside the U.S. or Canada, the scope of the PM mortality analysis is not expanded to include the two new studies.

Tables I.1 and I.2 in Appendix I provide information on the studies this analysis uses to quantify health effects. Table I.1 lists the studies relevant to PM exposure. Since the pollutants contributing to RH formation are similar to those contributing to PM formation, all studies listed for PM exposure are also applicable to the RH benefits analysis. As can be seen from the table, the various health and welfare effects studies have used different air quality indicators for particles. This analysis assesses benefits for both PM_{10} and $PM_{2.5}$. For functions using PM_{10} as an indicator, PM_{10} data for each alternative NAAQS is used. For functions using $PM_{2.5}$ as an indicator, $PM_{2.5}$ data for each alternative NAAQS is used. However, in the case of consumer cleaning cost savings, assumptions regarding the air quality indicator are necessary to evaluate the concentration-response function. (See section 12.8.2.5 for more details.)

Table I.2 lists the studies relevant to ozone exposure. The ozone benefits analysis uses data from a combination of clinical studies (where human subjects are exposed to various levels of air pollution in a carefully controlled and monitored laboratory situation) as well as epidemiological studies (where the relationship between ambient exposures to ozone and health effects in the human population are typically studied in a "natural" setting). The portion of the ozone benefits analysis using clinical studies evaluates the concentration-response functions for the total U.S. population as well as two sub-population groups: outdoor children and outdoor workers. These sub-populations are of particular interest because individuals in these sub-populations are believed to experience higher than average exposure to ozone due to the amount of time they spend outdoors as well as the level of physical activity they engage in while outdoors.

Not listed in Table I.2 but also included in the ozone benefits analysis is an additional health category related to toxic air pollutant emission reductions. This category is not listed in Table I.2 because a different methodology is used to estimate the benefits associated with this category. The Benefits TSD provides more information on this methodology (U.S. EPA, 1997a). As explained earlier, reductions in ozone concentrations are achieved by reducing emissions of VOC and NOx. Many of the components of VOC are listed as hazardous air pollutants (HAP) under section 112 of the Clean Air Act (CAA). HAPs, also known as “air toxics,” are associated with a variety of adverse human health effects such as cancer, reproductive and developmental effects, and neurological disorders, as well as adverse ecological effects. This analysis estimates the benefits of reduced exposure to carcinogens potentially resulting from implementation of a revised ozone NAAQS. The analysis focuses on three particular HAP’s expected to account for almost all cancer benefits from reductions of VOC HAP emissions: benzene, 1,3-butadiene, and formaldehyde. Non-cancer human health benefits and ecological benefits resulting from reduced emissions of air toxics are not quantified due to lack of available methods and data.

Other than the air toxics analysis described above, the majority of the models used in both the PM and ozone benefits analysis are epidemiological models. For most concentration-response functions, baseline incidences of health effects are needed for evaluation of the functions. For example, in the case of mortality, county-specific mortality rates were obtained for each county in the United States from the National Center for Health Statistics. Because those studies that estimated concentration-response functions for short-term exposure mortality considered only non-accidental mortality, county-specific baseline mortality rates used in the estimation of PM-related short-term exposure mortality are adjusted to reflect a better estimate of county-specific non-accidental mortality. Each county-specific mortality rate is multiplied by the ratio of national non-accidental mortality to national total mortality. County-specific baseline mortality rates are left unadjusted when applied to long-term exposure mortality functions because the study estimating a concentration-response function for long-term exposure mortality included all mortality cases.

Baseline incidence rates used for the year 2010 baseline are projected using current baseline incidence rates. The extent to which these current rates correspond to projected incidence rates in the year 2010, given either 2010 baseline or post-control PM and/or ozone concentrations, is not known.

This RIA assesses benefits estimates for the year 2010. As explained above, much of the benefits projections are calculated on a county-specific basis. Therefore, county-level population projections must be estimated for the year 2010. This analysis relies on population projections reported by the U.S. Census for the year 2010. However, these projections are available at the State level only. To estimate county-specific 2010 populations, the benefits model distributes the State-level projections to census block groups using the proportion of the 1990 State population accounted for by each block group. Thus, the geographic distribution of each State's population is retained. The population of the continental United States in the year 2010 is projected to be approximately 295.5 million.

12.7.3 Economic Valuation

12.7.3.1 Introduction

The social benefits associated with a change in the environment is the sum of each individual's willingness to pay for (or to avoid) the change. This analysis employs three techniques to value the social benefits resulting from reduced mortality and morbidity due to an environmental change.

One approach is called the "cost of illness" (COI) approach. This approach estimates the value of health improvements as the sum of the direct and indirect costs of illness: the health expenditures made and the loss of labor productivity. An advantage of the cost of illness approach is that economists can rely on observed human behavior. In addition, data are not difficult to collect. This method is commonly accepted by many researchers in the health care industry because it provides estimates for the value of a wide range of health effects. However, the COI approach does not provide a conceptually correct measure of willingness-to-pay (WTP) because it does not account for many factors associated with experiencing or avoiding an adverse health symptom (e.g., the value of discomfort an individual feels when experiencing an adverse health symptom). This analysis uses the COI approach to derive one component of the total value used to monetize the hospital admissions category but enhances that value by attempting to account for other components associated with illness, such as the value of avoiding pain caused by the illness.

The second approach involves conducting a survey and directly asking people what they would be willing to pay for a good, hypothetically assuming (contingent upon) the existence of a market for the good. This method, referred to as contingent valuation (CV), has been applied to a variety of non-market goods, including adverse health symptoms. CV is based on sophisticated survey techniques that may be able to yield valid and reliable WTP values. CV surveys also may address the issues of existence and bequest values because survey responses may include the moral satisfaction of contributing to public goods and charity. Although CV has been increasingly accepted in recent years, its application is controversial. Potential biases in willingness to pay estimates include hypothetical bias, strategic bias, starting point bias, vehicle bias, and information bias.

Finally, the value of a statistical life saved is based on a set of 26 studies, most of which are wage-risk studies. These studies attempt to estimate what workers are willing to pay to reduce their risks of premature mortality by statistical examinations of the wage premiums that are paid for higher risk jobs. The value of a statistical life year extended is based on the results of several studies that attempt to adjust the value of statistical lives saved by the life expectancy of individuals in the studies.

Each of the three methods discussed above is a method to estimate mean willingness to pay for a risk reduction or an adverse health effect avoided. WTP is the maximum amount of money an individual would pay such that the individual would be indifferent between having the good or service and having kept the money.

For both market and non-market goods, WTP values reflect individuals' preferences. Because preferences are likely to vary from one individual to another, WTP values for both market and non-market goods such as improvements in environmental quality are likely to vary from one individual to another. In contrast to market goods, however, non-market goods are public goods whose benefits are shared by many individuals. The individuals who "consume" the environmental quality improvement may have different WTP values for this non-market good. The total social value of the good is the sum of the WTP values of all individuals who consume the good.

If different subgroups of the population have substantially different WTP values for a unit risk reduction and substantially different numbers of units of risk reduction conferred upon them, then estimating the total social benefits by multiplying the population mean WTP value for a unit risk reduction by the predicted number of units of risk reduction could yield a biased result. For example, in the case of PM-induced premature mortality, there is evidence that most of those individuals receiving the benefits of a reduction in the probability of dying in the current year as a result of a reduction in ambient PM concentrations are the elderly. If WTP values for mortality risk improvement among the elderly are substantially different from WTP values for mortality risk improvement among younger individuals, then using the population mean WTP will give a biased result. This issue is addressed in this assessment of PM through the use of a statistical life-year extended approach in the low-end estimate. Unlike PM, there is not enough evidence at this time to assert that ozone mortality is age-dependent.

While the estimation of WTP values for a market good is not a simple matter, the estimation of a WTP value for a non-market good, such as a decrease in the risk of having a particular health problem, is substantially more difficult. Estimation of WTP values for decreases in specific health risks (e.g., WTP to avoid 1 day of coughing or WTP to avoid admission to the hospital for respiratory illness) is further limited by a paucity of information. Appendix I provides a brief description of the derivation of some of the more prominent WTP estimates used in this analysis. A more detailed description of the methodology is provided in the Benefits TSD (U.S. EPA, 1997a).

If exposure to pollution has any cumulative or lagged effects, then a given reduction in pollution concentrations in one year may confer benefits not only in that year, but in future years as well. Because this benefits analysis pertains to a single year only, any benefits achieved in other years are not included in this analysis. On the other hand, benefits even for a single year may not be fully realized until long after the year in which the exposure occurs. In this case it would be appropriate to discount such benefits. Because there is currently inadequate data to determine the lag with which various health benefits are realized, benefits are assumed to occur fully in the same year as exposure.

12.7.3.2 Valuation Estimates

Table 12.3 presents the WTP values available to monetize the reduced adverse health effects presented earlier in this chapter. Each value presented in Table 12.3 represents the point estimate of the monetary value associated with avoiding a unit of a given adverse health effect and is known as a unit dollar value. Although the WTP estimates presented in Table 12.3 are represented as point estimates, this analysis addresses the uncertainty associated with each of the unit dollar values. To further capture the plausible range of monetized values for premature mortality, the low-end estimate values these benefits using a life year extended rather than a lives saved approach. See Appendix I for more information on a sensitivity analysis of uncertainty.

The monetary values used in this analysis are generally consistent with monetary values reported in the Section 812(a) draft report, with the exception of the hospital admissions categories (U.S. EPA, 1997b). The section 812(a) analysis uses the COI approach to derive an economic value for the hospital admissions categories. However, since COI estimates do not measure values associated with pain and suffering (as well as other potential reductions in well-being) resulting from illness, they may significantly understate the true WTP value to avoid illness. For this reason, an adjustment factor is employed to scale the hospital admissions COI estimate upward to reflect a WTP estimate. Following the strategy employed by Chestnut, the hospital admissions COI estimate as reported in the section 812(a) draft report is multiplied by a factor of two. This factor is based on results from three studies providing evidence on COI/WTP ratios for the same study population addressing the same change in an air pollution-related effect. While this adjustment approach is based on limited evidence, the resulting hospital admissions valuation estimate is not clearly biased.

12.7.4 Health Benefits Aggregation Issues

Aggregation refers to the adding together of the monetized benefits associated with different health or welfare endpoints to derive a total monetized benefits attributable to a change in air quality. The dollar benefits from ozone reductions resulting from a specified air quality change is simply the sum of dollar benefits from the reductions in incidence of all non-overlapping health and welfare endpoints with which PM and/or ozone are associated.

Ideally, the effects of air pollution could be divided into mutually exclusive categories that, combined, account for all the effects. Even if health endpoint categories are overlapping, they are mutually exclusive, and can therefore be aggregated, if the populations for which their concentration-response functions are estimated are mutually exclusive. For example, respiratory illnesses among children and respiratory illnesses among adults are mutually exclusive categories. If two endpoints are overlapping, then adding the benefits associated with each endpoint results in double-counting some benefits. Although study-specific point estimates of dollar benefits

Table 12.3 Willingness-to-Pay Estimates (Mean Values)

Health Endpoint	Mean WTP Value per Incident (1990 $)
Mortality Life saved Life year extended	 $4.8 million $120,000
Hospital Admissions: All Respiratory Illnesses, all ages Pneumonia, age ≥ 65 COPD, age ≥ 65 Ischemic Heart Disease, age ≥ 65 Congestive Heart Failure, age ≥ 65 Emergency Visits for Asthma	 $12,700 $13,400 $15,900 $ 20,600 $ 16,600 $9,000
Chronic Bronchitis	$260,000
Upper Respiratory Symptoms	$19
Lower Respiratory Symptoms	$12
Acute Bronchitis	$45
Acute Respiratory Symptoms (any of 19)	$18
Asthma	$32
Shortness of Breath	$5.30
Sinusitis and Hay Fever	not monetized
Work Loss Days	$83
Restricted Activity Days (RAD) Minor RAD Respiratory RAD	 $38 not monetized
Worker Productivity	$1 per worker per 10% change in ozone
Visibility: residential recreational	$14 per unit decrease in deciview per household Range of $7.30 to $11 per unit decrease in deciview per household (see U.S. EPA, 1997a)
Household Soiling Damage	$2.50 per household per $\mu g/m^3$

*See the Benefits TSD for citations (U.S. EPA, 1997a).

associated with specific, possibly overlapping endpoints are reported separately in the technical supporting documentation to this RIA, the total benefits estimates presented in this chapter requires that only benefits from non-overlapping endpoints be included in the total calculation.

Appendix I provides a summarized description of the aggregation procedure used in this RIA. In general, four non-overlapping broad categories of health and welfare endpoints are included in the estimation of total dollar benefits in this analysis: (1) mortality, (2) hospital admissions, (3) respiratory symptoms/illnesses not requiring hospital admissions, and (4) welfare endpoints.

12.7.5 National Health Benefits Results

National health benefits estimates for PM and ozone are presented in Tables 12.4 through 12.10. Tables 12.4 and 12.5 present incidence and monetized results, respectively, for alternative

$PM_{2.5}$ standards. Tables 12.6 and 12.7 present benefits results for the selected PM_{10} standard. Tables 12.8 and 12.9 present incidence and monetized results, respectively, for alternative ozone standards. These results represent partial attainment of each alternative. PM benefits estimates are presented incremental from partial attainment of the current ozone and PM NAAQS. Ozone benefits estimates are presented incremental from partial attainment of the current ozone NAAQS, for the high-end estimate, and incremental from partial attainment of the current ozone and new PM NAAQS for the low-end estimate. Benefits estimates associated with the current standards are presented in Appendix C.

All health effects models are evaluated using baseline 2010 air quality and post-control or post-rollback air quality. Results produced by the benefits model represent the reduction in the number of incidences given imposition of a particular PM or ozone NAAQS upon the 2010 air quality baseline. These results are then monetized using WTP estimates.

Table 12.4 PM: National Annual Health Incidence Reductions[a]
Estimates are incremental to the current ozone and PM NAAQS: (year = 2010)

ENDPOINT[b]		Partial Attainment Scenario		
		High-end Est.	**Low- to High-end Est.**	**High-end Est.**
	Annual $PM_{2.5}$ ($\mu g/m^3$)	**16**	**15**	**15**
	Daily $PM_{2.5}$ ($\mu g/m^3$)	**65**	**65**	**50**
***1. Mortality[c]: short-term exposure**		4,900	3,300 - 15,600	5,700
long-term exposure		14,000		15,900
***2. Chronic Bronchitis**		56,000	45,000 - 75,000	80,000
Hospital Admissions:				
*3. all respiratory (all ages)		5,100	3,600 - 5,700	6,000
all resp. (ages 65+)		6,400	4,800 - 8,000	8,600
pneumonia (ages 65+)		2,300	1,800 - 2,900	3,100
COPD (ages 65+)		2,000	1,200 - 2,400	2,600
*4. congestive heart failure		1,700	1,200 - 2,100	2,300
*5. ischemic heart disease		1,900	1,200 - 2,400	2,600
***6. Acute Bronchitis**		17,700	12,000 - 20,000	21,000
***7. Lower Respiratory Symptoms**		265,000	179,000 - 299,000	320,000
***8. Upper Respiratory Symptoms**		45,000	36,000 - 60,000	65,000
shortness of breath		93,000	80,000 - 134,000	137,000
asthma attacks		349,000	235,000 - 392,000	416,000
***9. Work Loss Days**		2,799,000	1,900,000 - 3,148,000	3,313,000
***10. Minor Restricted Activity Days (MRADs)**		23,244,000	15,697,000 - 26,128,000	27,499,000

[a] numbers may not completely agree due to rounding

[b] only endpoints denoted with an * are aggregated into total benefits estimates

[c] mortality estimates must be aggregated using either short-term exposure or long-term exposure but not both due to double-counting issues

Table 12.5 PM : National Annual Monetized Health Benefits[a]
Estimates are incremental to the current ozone (0.12 ppm, 1-hr.) and PM NAAQS (50 µg/m^3 annual; 150 µg/m^3 daily)
(billions of 1990 $; year = 2010)

ENDPOINT[b]		Partial Attainment Scenario High-endEst.		
		High-end Est.	**Low- to High-end Est.**	**High-end Est.**
	Annual $PM_{2.5}$ (µg/m^3)	**16**	**15**	**15**
	Daily $PM_{2.5}$ (µg/m^3)	**65**	**65**	**50**
***Mortality[c]: short-term exposure long-term exposure**		$23.4 $67.0	$1.8 - $75.1	$27.5 $76.3
***Chronic Bronchitis**		$14.6	$11.7 - $19.4	$20.9
Hospital Admissions: *all respiratory (all ages) all resp. (ages 65+) pneumonia (ages 65+) COPD (ages 65+) *congestive heart failure *ischemic heart disease		 $0.064 $0.080 $0.036 $0.031 $0.028 $0.039	 $0.042 - $0.072 $0.060 - $0.100 $0.030 - $0.046 $0.024 - $0.038 $0.030 - $0.035 $0.030 - $0.049	 $0.076 $0.108 $0.049 $0.041 $0.038 $0.053
***Acute Bronchitis**		$0.001	$0.001 - $0.001	$0.001
***Lower Respiratory Symptoms** ***Upper Respiratory Symptoms** shortness of breath asthma attacks		$0.003 $0.001 $0.000 $0.011	$0.002 - $0.004 $0.001 - $0.001 $0.000 - $0.001 $0.008 - $0.013	$0.004 $0.001 $0.001 $0.015
***Work Loss Days**		$0.232	$0.156- $0.261	$0.275
***Minor Restricted Activity Days (MRADs)**		$0.892	$0.600 - $1.000	$1.100
TOTAL MONETIZED BENEFITS using short-term PM mortality using long-term PM mortality		 $39 $83	 $14.5 - $96.1	 $50 $99

[a] numbers may not completely agree due to rounding

[b] only endpoints denoted with an * are aggregated into total benefits estimates

[c] mortality estimates must be aggregated using either short-term exposure or long-term exposure but not both due to double-counting issues

Table 12.6 Proposed PM_{10} Standard (50/150 $\mu g/m^3$) 99th Percentile National Annual Health Incidence Reductions[a]

Estimates are incremental to the current ozone and PM NAAQS: (year = 2010)

		Partial Attainment Scenario
	Annual $PM_{2.5}$ ($\mu g/m^3$)	**50**
ENDPOINT[b]	**Daily $PM_{2.5}$ ($\mu g/m^3$)**	**150**
***1. Mortality[c]: short-term exposure**		360
long-term exposure		340
***2. Chronic Bronchitis**		6,800
Hospital Admissions:		
*3. all respiratory (all ages)		190
all resp. (ages 65+)		470
pneumonia (ages 65+)		170
COPD (ages 65+)		140
*4. congestive heart failure		130
*5. ischemic heart disease		140
***6. Acute Bronchitis**		1,100
***7. Lower Respiratory Symptoms**		10,400
***8. Upper Respiratory Symptoms**		5,300
shortness of breath		18,300
asthma attacks		8,800
***9. Work Loss Days**		106,000
***10. Minor Restricted Activity Days (MRADs)**		879,000

[a] numbers may not completely agree due to rounding

[b] only endpoints denoted with an * are aggregated into total benefits estimates

[c] mortality estimates must be aggregated using either short-term exposure or long-term exposure but not both due to double-counting issues

Table 12.7 Proposed PM_{10} Standard (50/150 $\mu g/m^3$) 99th Percentile National Annual Monetized Health Benefits Incidence Reductions[a]

Estimates are incremental to the current ozone (0.12 ppm, 1-hr.)
(billions of 1990 $;year = 2010)

ENDPOINT[b]		**Partial Attainment Scenario High-end Est.**
	Annual $PM_{2.5}$ ($\mu g/m^3$)	**50**
	Daily $PM_{2.5}$ ($\mu g/m^3$)	**150**
***1. Mortality[c]: short-term exposure**		$1.7
long-term exposure		$1.6
***2. Chronic Bronchitis**		$1.8
Hospital Admissions:		
*3. all respiratory (all ages)		$0.002
all resp. (ages 65+)		$0.006
pneumonia (ages 65+)		$0.003
COPD (ages 65+)		$0.002
*4. congestive heart failure		$0.002
*5. ischemic heart disease		$0.003
***6. Acute Bronchitis**		$0
***7. Lower Respiratory Symptoms**		$0
***8. Upper Respiratory Symptoms**		$0
shortness of breath		$0
asthma attacks		$0
***9. Work Loss Days**		$0.009
***10. Minor Restricted Activity Days (MRADs)**		$0.034
TOTAL MONETIZED BENEFITS		
using long term mortality		$3.4
using short term mortality		$3.5

[a] numbers may not completely agree due to rounding

[b] only endpoints denoted with an * are aggregated into total benefits estimates

[c] mortality estimates must be aggregated using either short-term exposure or long-term exposure but not both due to double-counting issues

Table 12.8 Ozone : National Annual Health Incidence Reductions[a]
Estimates are incremental to the current ozone NAAQS
(year = 2010)

ENDPOINT[b]	Partial Attainment Scenario		
	0.08 5th Max High-end Est.	**0.08 4th Max Low- to High-end Est.**	**0.08 3rd Max High-endEst.**
Ozone Health:			
***1. Mortality**	80	0 - 80	120
Hospital Admissions			
*2. all respiratory (all ages)	280	300 - 300	420
all respiratory (ages 65+)	2,300	2,330 - 2,330	1,570
pneumonia (ages 65+)	860	870 - 870	600
COPD (ages 65+)	260	260 - 260	200
emer. dept. visits for asthma	120	130 - 130	180
***3. Acute Respiratory Symptoms** (any of 19)	28,510	29,840 - 29,840	42,070
asthma attacks	60	60 - 60	90
MRADs	620	650 - 650	920
***4. Mortality from air toxics**	1	1 - 1	2
Ancillary PM Health:			
***1. Mortality[c]: short-term exp.**	60	0 - 80	110
long-term exposure	180	0 - 250	340
***2. Chronic Bronchitis**	400	0 - 530	690
Hospital Admissions:			
*3. all respiratory (all ages)	70	0 - 90	120
all resp. (ages 65+)	50	0 - 60	80
pneumonia (ages 65+)	20	0 - 20	30
COPD (ages 65+)	10	0 - 20	20
*4. congestive heart failure	10	0 - 20	20
*5. ischemic heart disease	10	0 - 20	20
***6. Acute Bronchitis**	290	0 - 400	530
***7. Lower Respiratory Symptoms**	3,510	0 - 4,670	6,190
***8. Upper Respiratory Symptoms**	320	0 - 430	570
shortness of breath	800	0 - 1,220	1,660
asthma attacks	4,210	0 - 5,510	7,200
***9. Work Loss Days**	38,700	0 - 50,440	66,160
***10. Minor Restricted Activity Days (MRADs)**	322,460	0 - 420,300	551,300

[a] numbers may not completely agree due to rounding

[b] only endpoints denoted with an * are aggregated into total benefits estimates

[c] PM mortality estimates must be aggregated using either short-term exposure or long-term exposure but not both due to double-counting issues

Table 12.9 Ozone : National Annual Monetized Health Benefits Estimates[a]
Estimates are incremental to the current ozone NAAQS (0.12 ppm, 1-hour)
(billions of 1990 $; year = 2010)

ENDPOINT[b]	Partial Attainment Scenario: 0.08 5th Max High-end Est.	Partial Attainment Scenario: 0.08 4th Max Low- to High-end Est.	Partial Attainment Scenario: 0.08 3rd Max High-end Est.
Ozone Health:			
***1. Mortality**	$0.370	$0.000 - $0.380	$0.570
Hospital Admissions			
*2. all respiratory (all ages)	$0.004	$0.004 - $0.004	$0.006
all resp. (ages 65+)	$0.029	$0.029 - $0.029	$0
pneumonia (ages 65+)	$0.014	$0.014 - $0.014	$0.010
COPD (ages 65+)	$0.004	$0.004 - $0.004	$0.003
emer. dept. visits for asthma	$0.001	$0.001 - $0.001	$0.002
***3. Acute Respiratory Symptoms** (any of 19)	$0.001	$0.001 - $0.001	$0.001
asthma attacks	$0	$0 - $0	$0
MRADs	$0	$0 - $0	$0
***4. Mortality from air toxics**	$0.003	$0.006- $0.006	$0.011
Ancillary PM Health:			
***1. Mortality[c]: short-term exp.**	$0.300	$0 - $0.400	$0.520
long-term exposure	$0.870	$0 - $1.210	$1.640
***2. Chronic Bronchitis**	$0.110	$0 - $0.140	$0.180
Hospital Admissions:			
*3. all respiratory (all ages)	$0.001	$0 - $0.001	$0.001
all resp. (ages 65+)	$0.001	$0 - $0.001	$0.001
pneumonia (ages 65+)	$0	$0 - $0	$0
COPD (ages 65+)	$0	$0 - $0	$0
*4. congestive heart failure	$0	$0 - $0	$0
*5. ischemic heart disease	$0	$0 - $0	$0
***6. Acute Bronchitis**	$0	$0 - $0	$0
***7. Lower Respiratory Symptoms**	$0	$0 - $0	$0
***8. Upper Respiratory Symptoms**	$0	$0 - $0	$0
shortness of breath	$0	$0 - $0	$0
asthma attacks	$0	$0 - $0	$0
***9. Work Loss Days**	$0.003	$0 - $0.004	$0.005
***10. Minor Restricted Activity Days (MRADs)**	$0.012	$0 - $0.016	$0.020
TOTAL MONETIZED BENEFITS			
using short-term PM mortality	$0.790	$0.056	$1.300
using long-term PM mortality	$1.400	$1.785	$2.400

[a] numbers may not completely agree due to rounding

[b] only endpoints denoted with an * are aggregated into total benefits estimates

[c] PM mortality estimates must be aggregated using either short-term exposure or long-term exposure but not both due to double-counting issues

Table 12.10 RH : National Annual Monetized Health Benefits[a]
Estimates are incremental to the selected PM and ozone standards
(billions of 1990 $; year = 2010)

ENDPOINT[b]	1.0 deciview improvement in 15 years (0.67 deciview target)		1.0 deciview improvement in 10 years (1.0 deciview target)	
	Incidence Reductions Low- to High-end Est.	**Monetized Benefits Low- to High-end Est.**	**Incidence Reductions Low- High-end Est.**	**Monetized Benefits Low- to High-end Est.**
***Mortality[c]**	120 - 200	$0.060-$0.950	360 - 600	$0.130 - $2.900
***Chronic Bronchitis**	2,600 - 4,400	$660 - $1,100	3,500 - 5,900	$0.900 - $1.500
Hospital Admissions:				
*all respiratory (all ages)	140 - 230	$0.002 - $0.003	250 - 420	$0.003 - $0.005
all resp. (ages 65+)	290 - 490	$0.004 - $0.006	420 - 700	$0.005 - $0.009
pneumonia (ages 65+)	110 - 180	$0.002 - $0.003	150 - 250	$0.002 - $0.004
COPD (ages 65+)	90 -150	$0.001- $0.002	130 - 220	$0.002 - $0.003
*congestive heart failure	80 - 130	$0.001- $0.002	110 - 190	$0.002 - $0.003
*ischemic heart disease	80 - 140	$$0.002 - 0.003	130 - 210	$0.002 - $0.004
***Acute Bronchitis**	310 - 510	$0 - $0	530 - 880	$0 - $0
***Lower Respiratory Symptoms**	7,800 - 13,000	$0.000 - $0.000	14,000 - 23,000	$0.000 - $0.000
***Upper Respiratory Symptoms**	2,400 - 4,000	$0.000 - $0.000	3,100 - 5,200	$0.000 - $0.000
shortness of breath	1,600 - 2,700	$0.000 - $0.000	4,000 - 6,600	$0.000 - $0.000
asthma attacks	11,000 - 17,800	$0.001 - $0.001	20,000 - 33,000	$0.001 - $0.001
***Work Loss Days**	74,000 - 124,000	$0.006 - $0.010	140,000 - 230,000	$0.011 - $0.019
***Minor Restricted Activity Days (MRADs)**	620,000 - 1,032,000	$0.024 - $0.040	1,150,000 - 1,912,400	$0.044 - $0.073
TOTAL MONETIZED BENEFITS	N/A	$0.760 - $2.100	N/A	$1.100 - $4.500

[a] numbers may not completely agree due to rounding

[b] only endpoints denoted with a * are aggregated into total benefits estimates

[c] mortality estimates must be aggregated using either short-term exposure or long-term exposure but not both due to double-counting issues

Tables 12.4 and 12.5 present national annual health incidence reductions and the associated monetized benefits associated with partial attainment of the alternative $PM_{2.5}$ standards. Based on these results, partial attainment of the selected $PM_{2.5}$ would result in decreasing premature mortality within the range of 3,300 to 16,000 cases (depending on whether short-term exposure or long-term exposure mortality is included and on whether a threshold at 15 $\mu g/m^3$ or effects down to background are assumed). The selected standard would also be expected to reduce the development of chronic bronchitis by approximately 45,000 to 75,000 cases and hospital admissions for all respiratory illnesses by approximately 3,600 to 6,000 cases. Total annual monetized health benefits estimates associated with the selected standard are expected to be approximately \$14.5 billion when the estimate is based on the low-end assumptions and \$96 billion when the estimate is based on the high-end assumptions. These estimates are incremental to partial attainment of the current PM and ozone NAAQS. Incremental from the current standard in the year 2010, population estimates associated with people living in predicted $PM_{2.5}$ nonattainment counties are approximately: 23.6 million for the 16/65 standard; 45.5 million for the 15/65 standard; 52.0 million for the 15/50 standard.

Tables 12.6 and 12.7 present benefits results associated with the selected PM_{10} standard. Based on these results, partial attainment of the selected PM_{10} standard is expected to decrease premature mortality by approximately 350 cases, hospital admissions for all respiratory illness by approximately 200 cases and chronic bronchitis cases by approximately 7,000 cases. Total annual monetized health estimates associated with the selected standard are expected to be approximately \$3.4 billion to \$3.5 billion.

Tables 12.8 and 12.9 present national annual health incidence reductions and the associated monetized benefits associated with partial attainment of the alternative ozone standards. Note that ozone benefits include ancillary PM benefits for the high end estimate. Based on these results, partial attainment of the selected ozone standard is expected to decrease premature mortality by approximately 160-330 cases, hospital admissions due to all respiratory illnesses by approximately 300, and acute respiratory symptoms by approximately 30,000 cases. Total annual monetized benefits associated with the selected standard are expected to be approximately \$0.1 billion for the low-end estimate and \$2.1 billion for the high-end estimate.

Incremental from the current standard in the year 2010, population estimates associated with people living in predicted ozone nonattainment areas are approximately: 30.6 million people for the 0.08 5th max., 40.2 million people for the 0.08 4th max., and 62.2 million people for the 0.08 3rd max. standard.

Table 12.10 presents national annual health incidence reductions and monetized benefits estimates associated with the RH targets. Health benefits can be estimated for a RH target because the control strategies (described in chapter 8) implemented to reduce RH also reduce particulate concentrations. This commonality between the control strategies for the two different programs allows the benefits analysis to estimate health as well as visibility benefits attributable to the RH target. The RH benefits estimates are calculated incremental from partial attainment of both the selected PM and selected ozone standards. The method for estimating visibility changes is presented in chapter 8. As explained in chapter 8, the analytical baseline understates the visibility progress achieved by CAA-mandated controls and implementation of a new ozone standard over the period 2000 to 2010. Additionally, the RH benefits are affected by the inability to model full attainment of the selected $PM_{2.5}$ standard as well as the degree to which some Class I area counties reach background air quality conditions. Given this analytical baseline, benefits are calculated using air quality changes incremental from partial attainment of the selected $PM_{2.5}$ standard. Under a visibility target of 0.67 equivalent to a 1 deciview improvement in the haziest days over 15 years, premature mortality is expected to decrease by approximately 120 - 200 cases; the development of chronic bronchitis cases is expected to be reduced by 2,600 - 4,400 cases; and hospital admissions for all respiratory illnesses is expected to decrease by 140 - 230 cases. Total annual monetized health benefits estimates associated with the 0.67 visibility target is expected to be as much as $0.8 to $2.1 billion. Under a visibility target of 1.0 equivalent to a 1 deciview improvement in the haziest days over 10 years, premature mortality is expected to decrease by approximately 360 - 600 cases; the development of chronic bronchitis cases is expected to be reduced by 3,500 - 5,900 cases; and hospital admissions for all respiratory illnesses is expected to decrease by 250 - 420 cases. Total annual monetized health benefits estimates associated with the 1.0 deciview visibility target is estimated to be as much as $1.1 - $4.5 billion.

The monetized health benefits estimates presented in this section are likely to be underestimates of the total health benefits associated with these standards due to a number of data and modeling limitations. See section 12.10 for a discussion of these limitations.

12.8 WELFARE EFFECTS

12.8.1 Introduction

The term “welfare benefits” encompasses all benefits categories other than human health effects. This section presents the welfare benefits methodology and results associated with reductions in ambient PM and ozone. These results include the economic benefits associated with reductions in the yield of some ozone-sensitive important commercial crops and forests and reduction of nitrogen deposition in estuarine and coastal waters for alternative standards. Adequate data are currently available to assess economic benefits for the commodity crops studied in the National Crop Loss Assessment Network (NCLAN) project (discussed in section VII-D.2 of the U.S. EPA Staff Paper for Ozone, June 1996) and for fruits and vegetables grown in California. Data are also available to estimate potential reductions in yield of some important ozone-sensitive commercial forest species nationwide, and to calculate nitrogen deposition avoided in estuaries, visibility improvements, consumer cleaning cost savings, and enhanced worker productivity.

12.8.2 Welfare Benefits Methodology

A number of models are used to estimate the welfare benefits presented in this analysis. This section briefly describes the welfare benefits categories and the methods employed to estimate the economic benefits associated with them.

12.8.2.1 Commodity Crops

The economic value associated with varying levels of yield loss for ozone-sensitive commodity crops is analyzed using a revised and updated (Mathtech, 1994; Mathtech, 1995; U.S. EPA 1997a) Regional Model Farm (RMF) agricultural benefits model. The RMF is an agricultural benefits model for commodity crops that account for about 75 percent of all U.S. sales of agricultural crops (Mathtech, 1994). The results of the model are extrapolated to account for all commodity crops nationwide. A rough approximation of a national estimate can be calculated by proportionally scaling the monetized estimates to the entire market. It is recognized, however, that factors such as the sensitivity to ozone of crops not formally analyzed, regional air quality, and regional economics introduce considerable uncertainty to any approach that develops a national estimate. 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 attaining ambient air quality standards.

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 equilibriums, the model calculates the change in net consumers' and producers' surplus on a crop-by-crop basis. Dollar values are aggregated across crops for each standard. The total dollar value represents a measure of the change in social welfare associated with the policy scenario. 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 Act, 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. 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 Act 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 U.S. EPA, 1997a.

The benefits from the RMF commodity crops range from for partial attainment of the .08 ppm, 4th max. standard are $11 million. See Table 12.15.

12.8.2.2 Fruit and Vegetable Crops

There are currently no national-level economic models that incorporate fruits and vegetables, although more comprehensive modeling efforts are underway. A regional model, the California Agricultural Resources Model (CARM), has been developed and used by the California Air Resources Board. This model is used in this analysis to calculate the benefits of reducing ambient ozone on sensitive crops grown in California (Abt, 1995a). Among these sensitive crops are the economically important fruits and vegetables endemic to California and other states with similar climate, such as Florida and Texas. The crops included in the CARM analysis are: almonds, apricots, avocados, cantaloupes, broccoli, citrus, grapes, plums, tomatoes, and dry beans. In 1990, California crops accounted for almost 50 percent of the U.S. fruit and vegetable production. Results of the model are extrapolated to include 100 percent of the crops. The results of the model are extrapolated to account for fruits and vegetables grown nationwide. A rough approximation of a national estimate can be calculated by proportionally scaling the monetized estimates to the entire market. It is recognized, however, that factors such as the sensitivity to ozone of crops not formally analyzed, regional air quality, and regional economics introduce considerable uncertainty to any approach that develops a national estimate.

The California Air Resources Model (CARM) is a nonlinear optimization model of California agricultural practices which assumes that producers maximize farm profit subject to land, water, and other agronomic constraints. The model maximizes total economic surplus and predicts producers' shifts in acreage planted to different crops due to changing market conditions or resources. The version of the CARM used for this analysis is calibrated to 1990 production and price data. Similar to RMF, the CARM production and price data will be updated using USDA projections to 2005 (Abt, 1997). Although this update is not completed yet, the CARM results have been extrapolated to reflect estimates for the year 2005.

The benefits from the CARM fruits and vegetables for partial attainment of the .08 ppm, 4th max. standard are $23 million. See Table 12.15.

12.8.2.3 Commercial Forests

Any attempt to estimate economic benefits for commercial forests associated with attaining alternative ozone standards 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, 1997) of forestry sector benefits describes quantitatively the effect of ozone on tree growth and the demand and supply characteristics of the timber market. The analysis employs baseline and post control ozone data equivalent to, and consistent with, the data used for the RMF and CARM models. 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. While the Pye *et al*. and deSteiger, Pye *et al.* studies present estimates of O_3 damage to forest growth rates for a variety of wood types by region, they present no damage estimates for western hardwoods. As a result, the forestry sector benefit estimates exclude the potential benefits of improved growth rates for western hardwoods. However, hardwoods account for only about 11 percent of total western growing stocks. 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 full or partial attainment of alternative standards.

Table 12.11 presents estimates of the annual benefits to the commercial forestry sector for two ozone scenarios incremental to the current ozone standard: the 0.08 ppm, 3rd max partial attainment and full attainment. These benefits are estimates of the annual payments that society would be willing to pay over the period 2010 through 2040 for higher growth rates in commercial forests.

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 12.11. For example, the .08 ppm 3rd max standard under the full attainment scenario would generate about $370 million in undiscounted economic surplus to the U.S. economy during the year 2040 and result in about $3.69 billion additional forest inventories by 2040. The estimated annualized benefits for this scenario, $65 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. Also, the estimates presented in Table 12.11 are slightly conservative based on the interpretation of the Pye 1988 report versus the deSteiger and Pye 1990 article. Another reason for describing the estimates as conservative is the uncertainty that exists about the relationship between carbon assimilation and how assimilated products affect overall tree growth. A complicating factor is the tree aging process, since “the relative amount of photosynthetic to non-photosynthetic tissue changes with age” (Fox, 1995).

Table 12.11 Ozone: Estimated Annual Commercial Forestry Benefits[a] Incremental to the Current Ozone Standard
(millions of 1990 dollars in 2010)

Scenario	Annual Benefits
8-hr, 3rd max, partial attainment	$14
8-hr, 3rd max, full attainment	$65

12.8.2.4 Nitrogen Deposition in Estuarine and Coastal Waters

The December 1996 RIA did not estimate the benefits of reducing the amount of air-borne nitrogen which is entering our nation's estuaries. Excessive amounts of nitrogen entering our estuaries are linked with the outbreak of large algal blooms. The resulting large fish kills cause a decaying, odoriferous situation which can shut down local tourism. Partially in response to public comments which asked for some proof of the assumed size of these unquantified benefit categories, scientists from EPA and NOAA have developed a methodology to measure the potential benefits from the reduction of atmospheric nitrogen in the estuaries of the East Coast of the United States accrued from implementation of the PM and ozone NAAQS (US EPA, 1997c).

The benefits to surrounding communities of reduced nitrogen loadings resulting from various control strategies for atmospheric NOx emissions were calculated for 12 East and Gulf Coast estuaries, and extrapolated to all 43 Eastern U.S. estuaries. See Table 12.12. The 12 Eastern estuaries represent approximately half of the estuarine watershed area in square miles along the East coast. Benefits are estimated using an average, locally-based cost for nitrogen removal from water pollution (US EPA, 1997c). The benefits to the 12 estuaries are estimated at $112 million for partial attainment of the .08 ppm, 4th max. standard. The benefits for the Eastern U.S. are estimated at $193 million for partial attainment of the .08 ppm, 4th max standard. Total Eastern U.S. projections are made by scaling results based on watershed area

[a] annualized benefits computed over the period 2010 through 2040, discounted at a 7 percent annual rate

and NOAA surveys of nitrogen loadings. These benefits are probably below the actual benefits because they do not include: improved recreation, wildlife habitat, commercial fishing, and other public health benefits.

12.8.2.5 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. The visibility improvement is modeled on a county-specific basis. Based on the deciview measure, two types of valuation estimates are applied to the expected visibility changes: residential visibility and recreational visibility.

Table 12.12: Benefits To Estuaries From Reduced Nitrogen Deposition Due To Alternative PM2.5 and 8Hr Ozone NAAQS*

	PM2.5 15/50		0.08 / 4th max		0.08 / 5th max	
ESTUARY	**Reductions in Air N Load**	**Value ($ million)**	**Reductions in Air N Load** (thous. kg/yr)	**Value** ($ million)	**Reductions in Air N Load** (thous. kg/yr)	**Value** ($ million)
Albemarle/ Pamlico Sound	240	18	120	9	80	6
Cape Cod Bay	100	14	40	6	40	6
Chesapeake Bay	1,220	60	480	23	390	19
Delaware Bay	190	26	120	17	110	15
Delaware Inland Bays	10	1	0	0	0	0
Gardiners Bay	0	0	0	0	0	0
Hudson River/ Raritan Bay	180	25	140	19	120	17
Long Island Sound	180	42	130	30	110	26
Massachusetts Bay	80	11	40	6	40	6
Narragansett Bay	10	1	10	1	0	0
Sarasota Bay	10	1	0	0	0	0
Tampa Bay	0	0	10	2	10	2
TOTAL for the above 12	2,220	200	1,009	112	900	96
TOTAL for Eastern US	3,820	344	1,880	193	1,548	165

* Reductions and valuation incremental to current ozone and PM NAAQS and target the year 2010; ranges reflect partial attainment of alternative standards. Benefits valued at the average cost today of removing nitrogen from point- and non-point- water pollution controls. Numbers may not add up exactly due to rounding. Total Eastern US projections made by scaling results for the listed estuaries based on watershed area and NOAA surveys of nitrogen loadings.

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 county estimated to experience a change in visibility.

Recreational visibility refers to visibility conditions in national parks (referred to as Class I areas). Chestnut (Chestnut, 1997a) has developed a methodology for estimating the value to the U.S. public of visibility improvements in Class I areas. Based on contingent valuation studies, Chestnut calculates a household WTP for visibility improvements, capturing both use and non-use recreational values, and attempts to account for geographic variations in WTP.

Chestnut divides the recreational areas of the U.S. into three regions: California, Southwest, and Southeast. The regions are developed to capture differences in household WTP values based on proximity to recreational areas. That is, in-region respondents typically place higher value on visibility improvements at a local recreational area than out-of-region respondents. Chestnut reports both in-region WTP and out-of-region WTP for each of the three regions. Chestnut concludes that, for a given region, a substantial proportion of the WTP is attributable to one specific park within the region. This so called “indicator park” is the most well-known and frequently visited park within a particular region. The indicator parks for the three regions are Yosemite for California, the Grand Canyon for the Southwest, and Shenandoah for the Southeast. In accordance with the Chestnut methodology, this analysis calculates out-of-region and in-region benefits for a particular regions for a given change in Class I areas visibility.

In theory, summing benefits out-of-region and benefits in-region would yield the total monetary benefits associated with a given visibility improvement in a particular recreational region, which could then be summed across regions to estimate national benefits. However, as described earlier, this analysis also estimates benefits associated with residential visibility improvements. To reflect the uncertainties raised by the use of CV methodology, the low-end estimate does not included visibility improvements in non-indicator parks.

12.8.2.6 Consumer Cleaning Cost Savings

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. Table I.1 documents the function used to associate nationwide PM levels with household WTP to avoid the cleaning costs incurred for each additional $\mu g/m^3$ of PM.

Assumptions regarding the air quality indicator are necessary to evaluate the concentration-response function. For each alternative scenario, the function for household soiling damage, originally derived using total suspended particulates (TSP) as an indicator of PM, is evaluated using the indicator under consideration for that scenario. 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.

12.8.2.7 Worker Productivity

Crocker and Horst (1981) and U.S. EPA present evidence regarding the inverse relationship between ozone exposure and productivity in exposed citrus workers. This analysis applies the worker productivity relationship (reported as income elasticity with respect to ozone) to workers engaged in strenuous outdoor labor in the U.S. (approximately one percent of the population). Baseline income for these workers is reported as $73 per day. Table I.2 in Appendix I details the concentration response function.

12.8.3 National Welfare Benefits Results

Table 12.13 presents the welfare benefits associated with partial attainment of the alternative $PM_{2.5}$ standards. PM welfare benefits categories that are monetized in this analysis include: consumer cleaning cost savings, improved visibility and decreased nitrogen deposition. Based on the results presented in Table 12.13, total welfare benefits associated with the selected $PM_{2.5}$ standard range from $4.3 to $8.1 billion annually. These results are incremental to partial attainment of the current ozone and PM NAAQS.

Table 12.14 presents national annual welfare benefits estimates associated with the selected PM_{10} standard. Total annual monetized welfare benefits are estimated to be approximately $5 billion.

The welfare benefits associated with partial attainment of the alternative ozone standards are presented in Table 12.15. Monetized ozone welfare benefits categories include increased yields of commodity crops and fruits and vegetables, increased yields in commercial forests, decreased nitrogen deposition, improved visibility, consumer cleaning cost savings, and increased worker productivity. Based on the results presented in Table 12.15, total welfare benefits associated with the selected ozone standard are expected to be approximately $320 million annually. These results are incremental to partial attainment of the current ozone NAAQS.

Table 12.13 PM : National Annual Monetized Welfare Benefits[a]
Estimates are incremental to the current ozone (0.12 ppm, 1-hr.) and PM NAAQS (50 μg/m³ annual; 150 μg/m³ daily)
(billions of 1990 $; year = 2010)

		Partial Attainment Scenario		
		High-end Est.	Low- to High-End Est.	High-end Est.
	Annual $PM_{2.5}$ (μg/m³)	16	15	15
CATEGORY	Daily $PM_{2.5}$ (μg/m³)	65	65	50
Consumer Cleaning Cost Savings		$0.29	$0.37	$0.40
Visibility		$7.30	$3.96 - $7.80	$8.40
Nitrogen Deposition		N/E	N/E	$0.34
TOTAL MONETIZED BENEFITS		$7.54	$4.26 - $8.10	$9.10

N/E = not estimated

Table 12.14 PM : Proposed PM_{10} Standard (50/150 μg/m³) 99th Percentile National Annual Monetized Welfare Benefits[b]
Estimates are incremental to the current ozone (0.12 ppm, 1-hr.)
(billions of 1990 $; year = 2010)

		Partial Attainment Scenario High-end Estimate
	Annual $PM_{2.5}$ (μg/m³)	50
CATEGORY	Daily $PM_{2.5}$ (μg/m³)	150
Consumer Cleaning Cost Savings		$0.034
Visibility		$1.62
TOTAL MONETIZED BENEFITS		$1.6

[a] numbers may not completely agree due to rounding

[b] numbers may not completely agree due to rounding

Table 12.15 Ozone : National Annual Welfare Benefits Estimates[a]
Estimates are incremental to the current ozone NAAQS (0.12 ppm, 1-hour)
(billions of 1990 $, year = 2010)

CATEGORY	Partial Attainment Scenario		
	0.08 5th max	**0.08 4th max**	**0.08 3rd max**
Commodity Crops	$0.000	$0.011	$0.029
Fruits and Vegetables Crops	$0.015	$0.023	$0.023
Commercial Forests	N/E	N/E	$0.014
Nitrogen Deposition in Estuarine and Coastal Waters	$0.165	$0.193	$0.301
Consumer Cleaning Cost Savings	$0.002	$0.003	$0.004
Visibility	$0.056	$0.082	$0.102
Worker Productivity	$0.009	$0.009	$0.014
TOTAL MONETIZED BENEFITS	$0.250	$0.320	$0.490

N/E = not estimated

[a] numbers may not completely agree due to rounding

Table 12.16 presents national annual welfare benefits associated with the regional haze targets. These estimates are calculated incremental from partial attainment of both the PM and ozone selected standards. Monetized welfare benefits associated with reducing RH include consumer cleaning cost savings and improved visibility. The method for estimating visibility changes is presented in chapter 8. The same low-end and high-end assumptions are used in the visibility calculations as are used in the ozone and PM NAAQS benefits analyses. As explained in chapter 8, the analytical baseline understates the visibility progress achieved by CAA mandated controls and implementation of a new ozone standard over the period 2000 to 2010. Additionally, the baseline visibility target may be understated due to the inability to model full attainment of the selected $PM_{2.5.}$ Given this analytical baseline, benefits are calculated using air quality changes incremental from partial attainment of the selected $PM_{2.5}$ standard. Under a visibility target of 0.67 equivalent to a 1 deciview improvement in the haziest days over 15 years, economic benefits associated with consumer cleaning cost savings is estimated as $23 million; increased residential visibility is estimated to yield approximately $140 million; and increased visibility in Class I areas is estimated to yield approximately $340 - $850 million annually. Based on these results, total annual welfare benefits associated with the 0.67 deciview visibility target range from approximately $0.5 to $1 billion. Under a visibility target of 1.0 equivalent to a 1 deciview improvement in the haziest days over 10 years, economic benefits associated with consumer cleaning cost savings is estimated as $31 million; increased residential visibility is estimated to yield approximately $200 million; and increased visibility in Class I areas is estimated to yield approximately $370 - $920 million annually. Based on these results, total annual welfare benefits associated with the 1.0 deciview visibility target range from approximately $0.6 to $1.2 billion.

Table 12.16 RH : National Annual Monetized Welfare Benefits[a]
Estimates are incremental to the selected ozone and PM NAAQS
(billions of 1990 $; year = 2010)

CATEGORY	1.0 Deciview Improvement Over 15 Year (0.67 Deciview Target)	1.0 Deciview Improvement Over 10 Years (1.0 Deciview Target)
Consumer Cleaning Cost Savings	$0.023	$0.031
Visibility	$0.480 - $0.990	$0.57 - $1.13
TOTAL MONETIZED WELFARE BENEFITS	$0.50 - $1.01	$0.60 - $1.16

12.9 SUMMARY OF HEALTH AND WELFARE BENEFITS

The purpose of this section is to summarize the health and welfare benefits discussions presented earlier in this chapter. Annual monetized benefits have been presented separately for health and welfare effects. It is now possible to sum these health and welfare benefits to provide a more complete depiction of the total benefits expected to result from the various alternative standards examined in this RIA. The national monetized health and welfare benefits associated with PM, ozone and RH are presented in Tables 12.17 through 12.20.

The monetized benefit results presented in this benefits chapter cover a plausible range of estimates, from a high end to a low end, reflecting some of the uncertainties in this estimation. A Monte Carlo uncertainty analysis of the monetized benefits of attaining the $PM_{2.5}$ 15/65 standard, the PM_{10} 50/150 standard (99th percentile), and the ozone .08, 4th max. standard are presented in Benefits TSD (USEPA 1997a).

The reduction of ambient ozone concentrations is achieved through the control of precursor emissions. These precursor emissions consist of volatile organic compounds (VOCs) and nitrogen oxides (NOx). The cost analysis shows that many control measures employed in the ozone analysis are successful at removing both types of precursor emissions. In addition to

[a] numbers may not completely agree due to rounding

contributing to ozone formation, VOC and NOx react with other air-borne pollutants to form particulates. The PM air quality model, consolidated regional deposition model (CRDM), is used to estimate a quantifiable relationship between the ozone precursor emissions and ambient PM concentrations (i.e., the source-receptor relationship). An analysis of the ozone-related VOC and NOx emission reductions shows that particulate concentrations as estimated by the source-receptor matrix will decrease as a result of implementation of the ozone controls. These PM reductions are used to estimate ancillary PM benefits attributable to ozone control measures. The PM reductions attributable to implementation of the ozone control measures are then used in conjunction with all PM-related concentration-response functions to estimate total ancillary PM benefits. For example, all PM benefits categories listed as quantifiable in Table 12.1 are also applicable in the ozone benefits analysis because reductions of ozone precursor emissions will also reduce particulate concentrations.

The inclusion of ancillary PM benefits in the estimation of ozone benefits raises the issue of possible overlap between PM and ozone benefits estimation when using when using single-pollutant and co-pollutant models. A discussion of a possible overlap between PM and ozone mortality effects is presented here since mortality is the single largest contributor to total benefits for both PM and ozone reductions.

The PM-mortality relationship is currently more well established than the ozone-mortality relationship, and the magnitude of the PM effect on mortality appears to be significantly larger than that of ozone. To avoid falsely attributing the PM effects on mortality to ozone, therefore, inclusion of PM in the model was a criterion for inclusion of a study in the analysis of ozone and mortality. Most ozone-mortality studies met this criterion. It might be argued that the inclusion criteria for PM-mortality studies should mirror those of ozone-mortality studies, and that PM-mortality studies that did not include ozone in the concentration-response model should be excluded. The situation with PM-mortality studies, however, is not symmetrical to that of ozone-mortality studies. Because evidence of a significant association between ozone and premature mortality is quite recent, most PM-mortality studies have not included ozone in the concentration-response model. Excluding PM-mortality studies that did not include ozone would therefore substantially reduce the database on the relationship between

PM and mortality. Because it appears that the magnitude of the ozone effect on mortality is substantially smaller than that of the PM effect, and because PM and ozone are generally not highly correlated, the omission of ozone from a concentration-response model is likely to have only a very small effect on the estimated PM coefficient. Any potential double counting of benefits from adding the PM-related benefits estimated from models without ozone to the ozone-related benefits is therefore also likely to be quite small. Avoiding that small amount of possible double counting does not seem worth the substantial loss of information on the PM-mortality relationship that would result from restricting the analysis to only those studies with both PM and ozone in the model.

As shown in Table 12.17, total annual monetized health and welfare benefits associated with partial attainment of the selected $PM_{2.5}$ standard range from a high-end estimate of $104 billion to a low-end estimate of $19 billion. Table 12.18 shows that the high-end esitmate of total annual monetized health and welfare benefits associated with partial attainment of the selected PM_{10} standard range from $5.1 to $5.2 billion. Table 12.19 shows that total annual monetized health and welfare benefits associated with partial attainment of the selected ozone standard range from a high-end estimate of $2.1 billion to a low-end estimate of $0.4 billion. Table 12.20 presents total annual health and welfare benefits of alternative regional haze targets.

Table 12.17 PM: Summary of National Annual Monetized Health and Welfare Benefits[a]
Estimates are incremental to the current ozone and PM NAAQS
(billions of 1990 $; year = 2010)

Category[b]		**Partial Attainment Scenario**		
		High-end Est.	**Low- to High-end Est.**	**High-end Est.**
	Annual $PM_{2.5}$ (µg/m^3)	**16**	**15**	**15**
	Daily $PM_{2.5}$ (µg/m^3)	**65**	**65**	**50**
Health Benefits		$83	$15 to $96	$99
Welfare Benefits		$7.5	$4.3 to $8.1	$9
TOTAL MONETIZED BENEFITS		$90	$19 to $104	$107

Table 12.18 PM: Selected PM_{10} Standard (50/150 µg/m^3-- 99th percentile) Summary of National Annual Monetized Health and Welfare Benefits[a]
Estimates are incremental to the current ozone and PM NAAQS
(billions of 1990 $; year = 2010)

Category		**Partial Attainment Scenario High-end Est.**
	Annual PM_{10} (µg/m^3)	**50**
	Daily PM_{10} (µg/m^3)	**150**
Health Benefits		$3.4 to $3.5
Welfare Benefits		$1.6
TOTAL MONETIZED BENEFITS		$5.1 to $5.2

[a] numbers may not completely agree due to rounding

Table 12.19 Ozone: Summary of National Annual Monetized Health and Welfare Benefits[a]

Estimates are incremental to the current ozone and PM NAAQS
(billions of 1990 $; year = 2010)

Category	Partial Attainment Scenario		
	0.08 5th max High-end Est.	**0.08 4th max Low- to High-end Est.**	**0.08 3rd max High-end Est.**
Health Benefits	$1.4	$0.06 to $1.76	$2.4
Welfare Benefits	$0.25	$0.32 to $0.32	$0.5
TOTAL MONETIZED BENEFITS	$1.6	$0.4 to $2.1	$2.9

Table 12.20 RH: Summary of National Annual Monetized Health and Welfare Benefits[a]

Estimates are incremental to the selected ozone and PM NAAQS
(billions of 1990 $; year = 2010)

Category	1.0 Deciview Goal Over 15 Years (0.67 Deciview Target)		1.0 Deciview Goal Over 10 Years (1.0 DeciviewTarget)	
	Low-end Est.	**High-end Est.**	**Low-end Est.**	**High-end Est.**
Health Benefits	$0.8	$2.1	$1.1	$4.5
Welfare Benefits	$0.5	$1.0	$0.6	$1.2
TOTAL MONETIZED BENEFITS	$1.3	$3.2	$1.7	$5.7

[a] numbers may not completely agree due to rounding.

For a visibility target of 0.67 deciview (i.e., 1.0 deciview goal over 15 years), total annual monetized benefits are expected to range from $1.3 billion to $3.2 billion. For a visibility target of 1.0 deciview (i.e., 1.0 deciview goal over 10 years), total annual monetized benefits are expected to range between $1.7 billion and $5.7 billion. The $1.3 billion to $5.7 billion plausible benefits range presented in this analysis may be potentially overstated due to the inability to quantify all visibility improvements prior to implementation of the RH visibility targets. The benefits associated with the RH targets are directly linked to the eventual choices made by States on the reasonable progress targets for the period 2000 to 2010 of this RH analysis. Should the States submit appropriate State implementation plans (SIPs) with reasonable progress target levels set close to those that would be achieved by implementation of the NAAQS and other CAA requirements, then visibility improvements and benefits attributed to the RH program program will be minimal and could be as low as zero.

The monetized benefits presented above are likely to be under-represented for a number of reasons. First, modeling limitations prevent the estimation of ancillary ozone benefits associated with implementing control strategies designed to reduce particulate concentrations. For example, low NOx burners imposed on industrial combustion sources is a control measure selected in the PM cost analysis. In addition to contributing to PM formation, NOx is also an ozone precursor. Therefore, the use of low NOx burners to reduce particulate concentrations would also concurrently reduce ozone concentrations. To the extent that such controls are used in area that would be imposing them anyway to meet the ozone standard, they may provide additional ozone benefits beyond those included in this analysis. There are also reasons to think that the benefits presented here could be overstated. There are likely to be lags associated with the relationship between changes in air quality and changes in mortality (as measured by long-term studies) and on chronic bronchitis. EPA does not know the magnitude of this lag, but if it did, it would discount the benefits appropriately. EPA has not prepared such estimates here.

A second reason for the under-representation of monetized benefits is the inability to model achievment of RH targets. A discussion of the unquantified benefits as well as uncertainties associated with this analysis are presented in the next section.

Not presented in Table 12.17 are full attainment $PM_{2.5}$ benefits. Estimation of full attainment PM benefits is more uncertain than partial attainment estimation because the sources from which additional emissions will be reduced will not be identified until further monitoring and modeling are performed. The PM partial attainment analysis indicates that PM control strategies outside of a violating county are often selected to help the violating county attain the standard. This procedure often causes PM air quality to change across an entire region rather than only in the violating county. However, for benefits analysis purposes, it is not possible to predict PM air quality distribution changes in areas other than the small number of residual nonattainment counties. This procedure is likely to underestimate the benefits associated with full attainment because it does not account for possible air quality changes and the associated population outside of the few remaining residual nonattainment counties. This method of adjusting partial attainment PM air quality to a full attainment scenario will show only a small change between partial and full attainment of the alternative standards. In the residual nonattainment counties only, the air quality is adjusted using the procedure described in section 12.6. Because regionwide PM air quality changes cannot be estimated, full attainment visibility benefits are assumed equal to the partial attainment visibility benefits for this analysis. This is an underestimate of the full attainment visibility benefits expected from full attainment of the selected PM2.5 standard. This procedure results in a high-end estimate of annual full attainment monetized benefits (health and welfare) of approximately $110 billion and a low-end estimate of $20 billion for the 15/65 alternative. These full attainment PM estimates are presented incremental from full attainment of the current ozone and PM NAAQS.

Full attainment ozone benefits are also not presented in the summary table. The ozone full attainment benefits estimation is limited for the same reason as the PM full attainment analysis. For the high-end estimate in the ozone partial attainment analysis, emission reductions achieved by ozone controls are processed by the source-receptor matrix to predict ancillary PM air quality by ozone controls are processed by the source-receptor matrix to predict ancillary PM air quality changes attributable to each ozone alternative. However, full attainment ozone air quality is estimated by using the air quality adjustment procedure as described in section 12.6. The ozone air quality rollback procedure reduces baseline ozone concentrations to the level specified by each alternative ozone standard. However, it is not possible to know how the PM air quality distributions will change given full attainment of the ozone alternatives. It is not possible to adjust PM air quality distributions in the same manner because, in this context, there is no PM standard against which the PM distributions can be evaluated. Given this limitation, the ancillary PM benefits are proportionally scaled from partial to full attainment using the ratio of ozone full attainment to partial attainment benefits. Using this procedure, high-end annual full attainment monetized ozone benefits (health and welfare) are estimated to be approximately $8.5 billion and low-end benefits are estimated to be approximately $1.5 billion for the 0.08 4th max. alternative. These full attainment ozone estimates are presented incremental from full attainment of the current ozone NAAQS.

12.10 ANALYTICAL UNCERTAINTIES, LIMITATIONS, AND POTENTIAL BIASES

12.10.1 Introduction

Given incomplete information, this national benefits analysis yields inexact results because associated with any estimate is the issue of uncertainty. Potentially important sources of uncertainty exist and many of these are summarized in Table 12.21. 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.

Table 12.21 Identified Sources of Uncertainty in Benefits Estimation

1. Post-Control Air Quality Estimation
1.1 CRDM: The degree to which the CRDM reflects post-control PM air quality
1.2 Air Quality Rollback: The degree to which the air quality rollback procedures reflect future air quality distributions
2. Concentration-Response Relationships
2.1 Mean Value of concentration-response functions
2.2 Mean population: How well the mean population (Mβ) approximates that value of β, that if used in all counties, would yield the same results as would be obtained if county-specific βs were used?
2.3 Future-year concentration-response functions: How similar will future-year concentration-response relationships compare to current concentration-response relationships?
2.4 Correct functional form of each concentration-response relationship
2.5 For crops, the application of exposure-response functions from the NCLAN open-top chambers studies extrapolated to 2010 ambient air exposure patterns
2.6 For some fruit and vegetable crops, the use of alternative non-NCLAN exposure-response functions
3. Baseline Incidence Rates
3.1 Non-county-specific incidence rates: Some baseline incidence rates are not county-specific (e.g., those taken from the epidemiological studies) and may not accurately represent the actual county-specific rates
3.2 Future baseline incidence rates: How similar will future baseline incidence rates compare to current baseline incidence rates?
3.3 Population projections: How well will the population projections compare to actual populations in the year 2010?
4. Economic Valuation
4.1 Willingness-to-Pay estimates: The true distribution associated with each WTP value is unknown
4.2 Future WTP estimates: How similar will future WTP estimates compare to current WTP estimates?
4.3 Valuation method: Does valuation based on mortality risk, or extensions to life better reflect WTP?
4.4 Discounting/Lags: Lags between exposure and incidence might affect benefits.
5. Aggregation of Monetized Benefits
5.1 Incomplete information for all benefit categories: Monetized benefit estimation is limited to those health and welfare endpoints for which concentration-response functions and WTP values are estimated
5.2 Possible double counting: Given that the pollutants have similar effects there may be double counting some of the benefits categories

12.10.2 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 PM, ozone, and RH rules cannot be estimated due to insufficient income elasticity information. Thus, all else equal, the benefit estimates presented in this analysis are likely to be understated.

12.10.3 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. Tables 12.1 and 12.2 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.

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. Indirectly, SOx emissions controls applied for the purpose of implementing the $PM_{2.5}$ standard are expected to result in considerable reductions of mercury (approximately 16%). Mercury's toxic effects include human neurotoxicity; fish deaths and abnormalities; plant damage (e.g., senescence, reduced growth, decreased chlorophyll content, leaf injury, and root damage); and impaired reproduction, liver damage, kidney damage, and neurotoxicity in birds and other mammals.

In addition to the above non-monetized health benefits, there are a number of non-monetized welfare benefits of PM and ozone 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. In a recent attempt to estimate the "marginal" value (changes in quantity or quality) of ecosystem services, Costanza *et al*. (1997) state that policy decisions often give little weight to the value of ecosystem services because their value cannot be fully quantified or monetized in commercial market terms. Costanza *et al*. warn that "this neglect may ultimately compromise the sustainability of humans in the biosphere". 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. Just the value of the cultural services (i.e., aesthetics, artistic, educational, spiritual and scientific) may be considered infinite by some, albeit in the realm of moral considerations. 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 selected ozone NAAQS. Experts also believe that the effect of ozone on plants is both cumulative and long-term. The specific non-monetized benefits from ozone reductions in ambient 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 (e.g., Grand Canyon National Park); 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).

Infant Mortality

A recent study in the U.S. has found an association between infant mortality and PM_{10} (Woodruff et al., 1997). This conclusion is similar to conclusions in previous studies (Ministry of Public Health, 1954; Bobak et al., 1992; Knobel et al., 1995 and Penna et al., 1991). These last 3 studies were reviewed by the CASAC but not relied on by EPA in standard setting. The most recent study finds that high PM_{10} exposure is associated with increases in total infant mortality. Evaluation by cause of death finds a higher association for respiratory mortality and sudden infant death syndrome for normal birthweight infants. Although the association between PM exposure and increased postneonatal mortality risk is important, this category could not be included in the quantified benefits analysis because the new study was not published at the time the benefits analysis was conducted.

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.

Mercury Emission Reductions

Emissions of mercury from human activity are thought to contribute between 40 to 75 percent of the current total annual input of mercury to the atmosphere. This RIA imposes a national SOx strategy for the purpose of implementing the $PM_{2.5}$ alternatives. From the 2010 baseline, the SOx strategy is estimated to reduce 11 tons of mercury, which is approximately a 16 percent reduction.

Once emitted to the atmosphere, mercury can deposit to the earth in different ways and at different rates, depending on its physical and chemical form. The form of mercury emitted influences its atmospheric fate and transport, as do conditions specific to its site of release. The result is that mercury deposition is a local, regional, and global issue. Mercury can be deposited directly to water bodies or can be transported from land by run-off and enter many different types of water bodies. The water bodies contain microorganisms that have the metabolic capability to carry out chemical reactions which bind mercury to methyl groups, producing methylmercury. Methylmercury is the form of mercury to which humans and wildlife are generally exposed, usually from eating fish which have accumulated mercury in their muscle tissue.

Methylmercury is biologically concentrated or bioaccumulated. That is, an animal at a higher position in the foodweb may have mercury concentrations thousands of times higher than an animal at a lower position in the foodweb. The transfer of mercury in the foodweb to progressively higher concentrations in large fish is key to understanding how release of mercury to the atmosphere results in exposure to high concentrations of mercury in fish, and ultimately humans and wildlife which consume fish. Humans are most likely to be exposed to methylmercury through fish consumption, although exposure may occur through other routes as well. In addition, mercury is a known human toxicant which has been associated with occupational exposure and with exposure through consumption of contaminated food. The range of neurotoxic effects can vary from subtle decrements in motor skills and sensory ability to tremors, inability to walk, convulsions, and death. Neurotoxicity can also affect a developing embryo or fetus.

The environmental impacts of mercury on fish include death, reduced reproductive success, impaired growth, and developmental and behavioral abnormalities. Exposure to mercury can also cause adverse effects in plants, birds, and mammals. Effects of mercury on plants include plant senescence, growth inhibition, decreased chlorophyll content, leaf injury, root damage, and inhibited root growth and function. Reproductive effects are the primary concern for avian mercury poisoning and can include liver and kidney damage as well as neurobehavioral effects. Although clear causal links between mercury contamination and population declines in various wildlife species have not been established, mercury may be a contributing factor to population declines of the endangered Florida panther and the common loon.

Current levels of mercury in freshwater fish in the U.S. are such that advisories have been issued in 37 states warning against the consumption of certain amounts and species of fish that are contaminated with mercury. Seven states have statewide advisories. Such widespread contamination is a concern for several reasons including: potential health risk to people who continue to catch and eat fish from these waters; economic losses to tourism, commercial and recreational fisheries; health and economic impacts to people, including subsistence fishers, who can no longer eat fish from these waters.

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, 1995b), 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. While recognizing this limitation, an estimate of ozone-induced damage to ornamentals can be made based on data assessing retail expenditures on environmental horticulture at $23 billion in 1991 (Abt, 1995b). If only half of a percent of public expenditures on ornamentals could be traced to ozone-induced damage avoided with a revised ozone standard, then benefits would amount to $115 million.

Aesthetic Injury to Forests

Ozone is a regionally dispersed air pollutant that has conclusively been shown 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 documenting 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 (U.S. 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 (U.S. 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 national benefits of improved forest aesthetics expected to occur from the selected ozone standard. 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 changes to the ozone NAAQS 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 (U.S. EPA, 1993). 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 Denver, this phenomenon has been named the "brown cloud." 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 in terms of being able to see through it, 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., Grand Canyon National Park), tree seedlings for 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. For example, the National Acid Precipitation Assessment Program (NAPAP) reports that user values for visibility changes at recreation sites in the east and west are in the range of $1 to $10 per visitor per day. Similarly, estimates of the economic effects of acidic deposition damages on recreational fishing in the Adirondack region of New York range from $1 million to $13 million annually.

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). Approximately 75 percent (70 -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).

Elsewhere in this analysis, it is estimated that a 0.08 3rd max ozone standard would result in NOx emissions reductions of approximately 0.3 million tons/yr for partial attainment or 1.4 million tons/yr for full attainment from a 2010 baseline. These reductions are roughly equivalent to 1 - 6 percent of 1990 emission levels (i.e., the approximate year of the NAPAP deposition estimates).

NOx reductions resulting from a 0.08 3rd max ozone NAAQS could therefore, in theory, increase the nitrogen fertilization requirement for wheat from 0 - 0.03 percent for partial attainment and from 0 - 0.17 percent for full attainment. For corn, the increase would be from 0 - 0.01 percent for partial attainment and from 0 - 0.08 percent for full attainment. However, given the extremely small magnitude of these increases, it is highly unlikely that farmers could detect them and increase their fertilization application accordingly nor even control their nitrogen applications with this degree of precision.

Information on the effects of changes in passive nitrogen deposition on forest lands 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 in could have negative effects on forest and vegetation growth in ecosystems where nitrogen is a limiting factor (U.S. EPA, 1993).

However, there is evidence that forest ecosystems in some areas of the United States are nitrogen saturated (U.S. 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 to meet health and welfare-based standards 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. EPA is not currently able to adequately quantify these effects for the purpose of valuing benefits for these standards. If EPA were able to do so it would attempt to quantify these effects.

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 (U.S. 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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