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BENEFIT AND NET BENEFIT ANALYSIS OF

ALTERNATIVE NATIONAL AMBIENT AIR QUALITY

STANDARDS FOR PARTICULATE MATTER

VOLUME I

BENEFIT AND NET BENEFIT ANALYSIS OF ALTERNATIVE NATIONAL AMBIENT AIR QUALITY STANDARDS FOR PARTICULATE MATTER

VOLUME I

Prepared for:

Benefits Analysis Program
Economic Analysis Branch
Strategies and Air Standards Division
Office of Air Quality Planning and Standards

U.S. ENVIRONMENTAL PROTECTION AGENCY
Research Triangle Park, North Carolina

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EPA PERSPECTIVE

There has been growing concern with the effectiveness and burden of regulations imposed by the Federal government. In order to improve the process by which regulations are developed, Executive Order 12291 was issued. The order requires that Federal agencies develop and consider, to the extent permitted by law, Regulatory Impact Analyses (RIA) for the proposal and promulgation of regulatory actions which are classified as major. According to the order, a significant component of the RIA is to be an economic benefit and benefit-cost analysis of the regulatory alternatives considered. Under the Clean Air Act, the Administrator of EPA may not consider economic and technological feasibility in setting National Ambient Air Quality Standards (NAAQS). Although this precludes consideration of benefit cost analyses in setting NAAQS, it does not necessarily preclude consideration of benefit analyses for that purpose.

In full support of the Executive Order, the EPA commissioned Mathtech, Inc. to accomplish an economic benefit and benefit-cost analysis of some of the alternatives that were thought likely to be considered in the development of proposed revisions to the NAAQS for particulate matter (PM). The report, entitled "Benefit and Net Benefit Analysis of Alternative National Ambient Air Quality Standards for Particulate Matter," documents the results of the contractor's study. One of the major objectives of the study was to give a better understanding of the complex technical issues and the resource requirements associated with complying with the spirit of the Order for the NAAQS program. In order to achieve this objective, the contractor was given a wide range of latitude in the use of data, analytic methods, and underlying assumptions.

It is important to stress that the benefit analysis portion of the Mathtech study has not had a role to date in the development of proposed revisions to the NAAQS for particulate matter. Staff recommendations currently under consideration are based on the scientific and technical information contained in two EPA documents. They are the "Air Quality Criteria for Particulate Matter and Sulfur Oxides" and the "Review of the National Ambient Air Quality Standards for Particulate Matter: Assessment of Scientific and Technical Information, OAQPS Staff Paper." These documents have undergone extensive and rigorous review by the public and the Clean Air Scientific Advisory Committee in accordance with the Agency's established scientific review policy. Although the Mathtech study reflects the "state-of-the-art" in particulate matter benefit analysis, the approach and results have not been subjected to a comparable extensive peer review process. In addition, some EPA staff have raised questions regarding the approach taken in the analysis and the significance of the results for standard setting purposes under the Act. These circumstances do not necessarily preclude use of the benefit analysis in some manner after appropriate peer review and further consideration of the questions that have been raised.

BENEFIT AND NET BENEFIT ANALYSIS OF ALTERNATIVE NATIONAL AMBIENT AIR QUALITY STANDARDS FOR PARTICULATE MATTER

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PREFACE

This report was prepared for the U.S. Environmental Protection Agency by Mathtech, Inc. The report is organized into five volumes containing a total of 11 sections as follows:

ACKNOWLEDGMENTS

While preparing this report, we had the benefit of advice, comments and other assistance from many individuals. Allen Basala, the EPA Project Officer, and James Bain, former Chief of the Economic Analysis Branch (EAB), were especially helpful. They provided both overall guidance on project direction as well as technical review and comment on the report. Others in EAB who assisted us included Thomas Walton, George Duggan, and John O'Connor, the current Chief of EAB.

Others within EPA/OAQPS who reviewed parts of the report and assisted in various ways included Henry Thomas, Jeff Cohen, John Bachman, John Haines, Joseph Padgett, and Bruce Jordan.

Several individuals within EPA/OPA also provided comments or assistance at various stages of the project. These included Bart Ostro, Alex Cristofaro, Ralph Luken, Jon Harford, and Paul Stolpman.

Others outside EPA who reviewed parts of the report and provided comments included V. Kerry Smith, Paul Portney, Lester Lave, Eugene Seskin, and William Watson. Other Mathtech staff who assisted us in various ways were Donald Wise, Gary Labovich, and Robert J. Anderson. We also appreciate the assistance of Al Smith and Ken Brubaker of Argonne National Laboratory who conducted the parallel analysis of control costs and air quality impacts.

Naturally, it was not possible to incorporate all comments and suggestions. Therefore, the individuals listed above do not necessarily endorse the analyses or conclusions of the report.

The production of a report this length in several draft versions, each under a tight time constraint, is a job which taxes the patience and sanity of a secretarial staff. Carol Rossell had this difficult task and managed ably with the assistance of Deborah Piantoni, Gail Gay, and Sally Webb. Nadine Vogel and Virginia Wyatt, who share the same burden at EAB, also assisted us on several occasions.

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SECTION 1

THE BENEFIT ANALYSIS

INTRODUCTION

This report develops estimates of the benefits and net benefits of alternative national ambient air quality standards for particulate matter (PM). The report has been prepared to assist the U.S. Environmental Protection Agency in responding to the requirements of Executive Order 12291 which requires an analysis of the costs, benefits, and net benefits of major regulatory initiatives (1). This section is a summary of the benefit analysis results and methods documented in detail in Sections 3 through 11 of the report.

Benefit estimates alone are not sufficient to identify the economically preferred standard. The costs of attaining and maintaining the standards must also be considered. The benefits and costs of the alternative standards are compared in Section 2 of this report and the estimated net benefits are calculated. The cost estimates were developed by another contractor using analytical methods described in a separate report (2).

While cost analyses for new regulatory initiatives have been routinely developed by the U.S. Environmental Protection Agency, benefit analyses have only recently been undertaken. Benefit analysis in the past has been hindered primarily by limitations of data and methods available for measuring health and welfare effects of air pollution.

Recognition of the technical complexities confronting benefit analysis suggests use of an analysis strategy which has three key elements:

- Insuring that the analysis identifies and makes use of the best data and information currently available.
- Incorporating validation checks and sensitivity analyses into the analysis at each stage where technical uncertainty is present.
- Using a range of estimates or methods for valuing health improvements.

These efforts help identify the degree of uncertainty present and provide greater assurance about the quality of the results.

Section 1 is divided into nine parts including this introductory section. The other eight parts discuss: the scope of the analysis; the method of analysis; the air quality scenarios; the indices used to measure air quality; the procedures for measuring and valuing human health improvements; the benefit estimates by benefit type; the aggregate benefits; and the conclusions.

SCOPE OF THE BENEFIT ANALYSIS

Air Quality Standards

The benefit analysis examines several alternative ambient PM standards. The alternative standards involve various combinations of particle size measures, allowable ambient concentrations, implementation dates, and averaging times. The standards considered are a subset of those analyzed in the EPA's cost analysis and air quality modeling effort (2). While the alternatives do not exhaust the list of possibilities, they do include the current primary and secondary standards, and a variety of the alternative revisions to those standards. By design, the primary standard is intended to protect human health, while the secondary standard is to provide protection of the public welfare.

Coverage of Effects/Benefit Categories

Table 1-1 lists the major health and welfare effects categories potentially relevant in the consideration of alternative PM standards. In the health category, effects of interest include mortality and various types of acute and chronic morbidity. The EPA/OAQPS Staff Paper (3) indicates that the potentially relevant morbidity includes effects on respiratory mechanics and symptoms, aggravation of existing respiratory and cardiovascular disease, impairment of the body's defense mechanisms, damage to lung tissues, and carcinogenesis. The benefit analysis is able to provide partial coverage of these effects, with emphasis on mortality and acute and chronic respiratory effects. Currently available data and methods limit the scope of coverage.

In the welfare area, the benefit analysis emphasizes residential soiling effects and, to a lesser extent, industrial soiling. Available data and methods preclude consideration of soiling in the commercial,

Table 1-1

EFFECTS CATEGORIES POTENTIALLY RELEVANT TO ALTERNATIVE PM STANDARDS

• Health Effects	• Acidic Deposition
- Mortality	- Aquatic Life
- Acute Morbidity	- Crops & Forests
- Chronic Morbidity	- Materials
• Soiling & Materials Damage	• Climatic Effects
- Residential Facilities	- Temperature
- Commercial & Industrial Facilities	- Precipitation
- Governmental & Institutional Facilities	
	• Non-User Benefits
• Visibility Effects	
	- Bequest Value
- Regional Haze	- Existence Value
- Plume Blight	- Option Value

governmental, institutional, and most industrial sectors. Acidic deposition and regional haze are believed to be primarily associated with fine particles such as sulfates. It is difficult to predict whether and to what extent fine particle concentrations will be reduced by the control strategies required to attain the alternative PM standards under consideration. These effects are omitted from the analysis. Incidents of plume blight may be reduced also and this is not considered in the analysis. Little or no information is available on the climatic effects of alternative PM concentrations. Non-user benefits such as bequest value (the value placed on preserving a clean environment for future generations) are also not estimated.

The coverage of potentially relevant effects categories is thus only partially complete in terms of numbers of categories and coverage within categories. In this respect, the benefit estimates in this report may be conservative estimates of actual benefits.

OVERVIEW OF THE STUDY APPROACH

The time schedule for the analysis did not allow the undertaking of new effects studies. In view of this constraint, the basic strategy in the analysis is to make use of existing research results concerning the health and welfare effects of ambient particulate matter. That is, the existing research literature is identified, classified, and reviewed. Next, the best available studies for purposes of a benefit analysis are selected. Finally, the quantitative relationships (e.g., concentration-response functions) in these studies are used to estimate the benefits associated with the alternative PM standards under consideration. A more detailed overview of these steps is provided in the subsections that follow.

Identification and Classification of Existing Research Studies

For purposes of this analysis, the existing research literature on health and welfare effects is classified into the following major categories and subcategories:

- Health effects studies in the epidemiology literature including studies of
    - Mortality due to acute (short-term) exposures.
    - Acute morbidity due to acute exposures.
    - Acute morbidity due to chronic (long-term) exposures.
    - Chronic morbidity due to chronic exposures.
- Health effects studies in the economics literature including studies of
    - Mortality due to chronic exposures.
    - Acute morbidity due to chronic exposures.
    - Chronic morbidity due to chronic exposures.
- Soiling and materials damage studies including studies of effects in the
    - Household sector.
    - Manufacturing sector.

As noted previously, available studies and data limit the focus of this analysis to health effects and soiling or materials damage effects. The study areas listed above represent the spectrum of available literature in these effects areas. Visibility studies are also available and are identified in the analysis but, as noted previously, may not be applicable to the PM control strategies under consideration.

Note that in the list above, a distinction is made between health studies in the epidemiology literature and those in the economics literature. While there are technical similarities between these two groups of health studies, the studies are treated separately in the EPA Criteria Document (4). The two groups are thus kept separate in this analysis to allow comparison and separate use of their results.

Two additional literature areas are also identified. These include:

- Property value studies.
- Labor market (hedonic wage) studies.

The basic benefit estimates in this analysis are developed using the studies in the health and soiling effects areas listed earlier. Property value and hedonic wage studies provide an alternative method for estimating air pollution control benefits. They are thus used in this analysis to provide independent benefit estimates which can serve as a validation check on the basic benefit results.

Review and Selection of Best Available Studies

In each of the literature areas listed above, a comprehensive review and critique of the available research is undertaken. The starting points for this review are the EPA Criteria Document and the EPA/OAQPS Staff Paper for particulate matter. The objective of the review is to identify the best available studies for a benefit analysis in each area. Studies are evaluated in terms of such criteria as the soundness of the technical approach, the adequacy of the underlying data, the adaptability to estimating benefits, and the adequacy of study documentation.

An important feature of this review is a recognition that the various studies often differ widely in their findings concerning the effects of particulate matter. In the absence of a consensus, it may not be desirable to rely solely on one particular study for estimating the benefits in a particular category. Thus, in each benefit category, an effort is made to identify both a best available study and one or more plausible alternate studies. Separate benefit estimates are then developed for each of the selected studies in that category. Use of several plausible studies to calculate benefits helps illustrate both the possible range of benefits as well as the degree of uncertainty present in the existing research base.

Benefit Calculation Procedures

Benefit calculations in this analysis follow a three part procedure. In the first part (1), the quantitative relationships found in each selected study are used to calculate the benefits of a given air quality improvement. In the second part (2), the benefit results for the individual studies are used to estimate the benefits in each benefit category. Recall that this is required because more than one study is typically selected in each benefit category. In the third part (3), the results for each benefit category are used to estimate aggregate benefits. The third part cannot be accomplished by simply adding up all the benefit categories because some overlap may be present among the categories. The next several paragraphs provide further details on part (1), while parts (2) and (3) are discussed subsequently when the benefit results are presented.

Part (1) calculations encompass estimating the benefits implied by each study. These calculations are done according to a four or five step procedure. As shown in Figure 1-1, the first step is to identify the magnitude of the ambient air quality improvement that is estimated will occur in each county and year. This is the improvement achieved after implementation of a particular ambient standard, relative to a baseline situation reflecting air pollution controls already in place. The procedures for estimating air quality improvements are discussed in Section 9 of this report.

The second step involves estimating the health and welfare improvements that are expected to occur as a result of the improvement in ambient air quality. This step makes use of the research findings extracted from the literature review discussed previously. These findings include either linear or nonlinear relationships between health or welfare status and ambient concentrations of particulate matter. These relationships are discussed in detail in Sections 3 through 8 of this report. Note that estimates are required for each county and year in which there is an air quality improvement.

The third step is to impute an economic value to the estimated changes in health and welfare status. This is shown in the figure as Step 3a. For the health studies, this is perhaps the most difficult step conceptually. There is limited evidence on how to estimate the economic value of some changes in health status (e.g., improved lung function). For this reason,

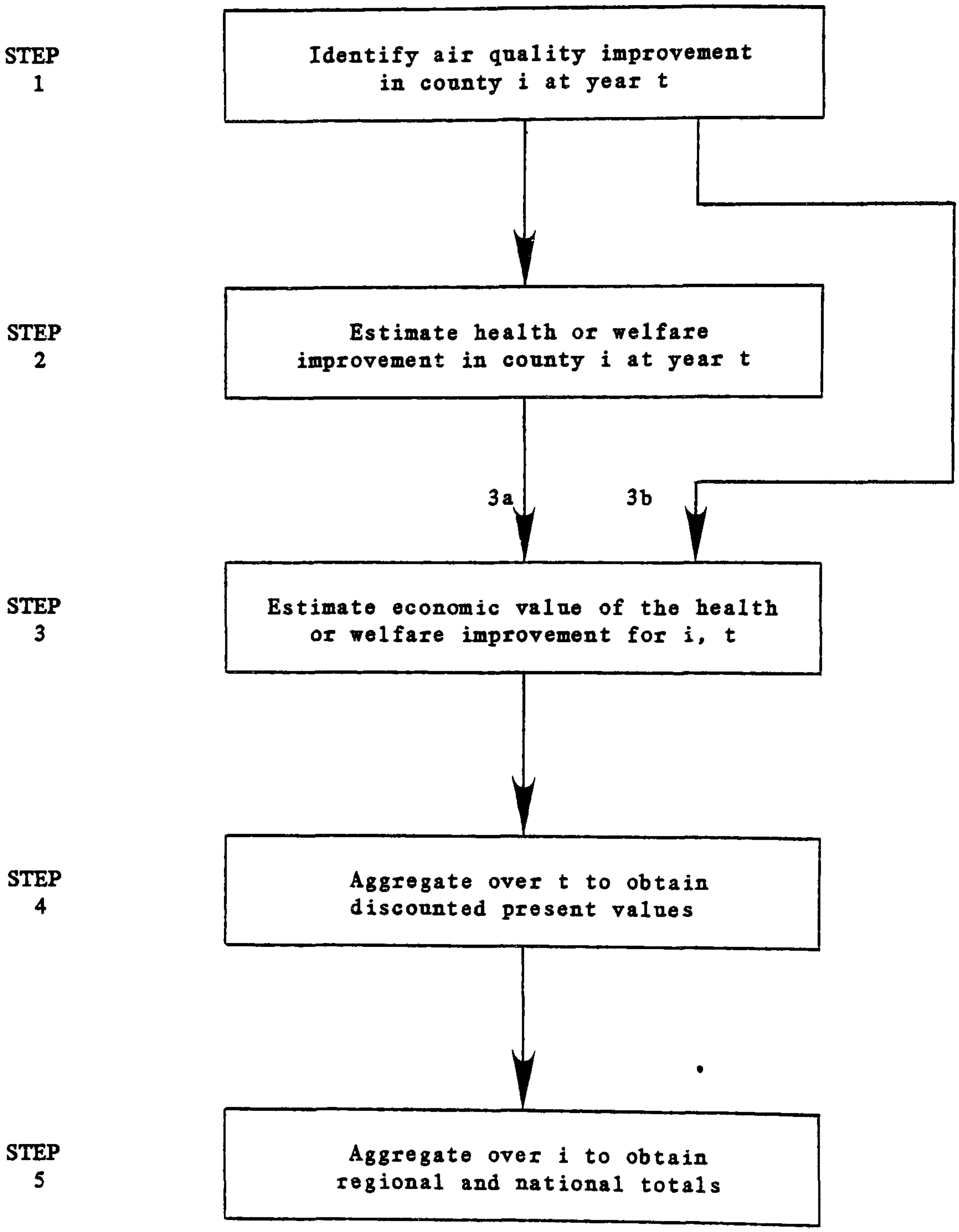

Figure 1-1. Basic steps in estimating benefits for an individual study

a variety of methods and estimates of value are employed in order to evaluate how they influence the results. Note also that in some cases it is possible to estimate economic values directly from the air quality improvement. This is shown in the figure as Step 3b. Property value studies are an example of this approach. These studies analyze variations in residential property values within a metropolitan area to identify the variation due to perceived differences in environmental amenities such as air quality, while statistically controlling for variation due to differences in housing quality and other locational attributes. Studies of this type thus allow direct estimates of the perceived economic value of environmental improvements.

The fourth step is to aggregate results over a specific period of years to obtain discounted present values. The number of years depends on the particular standard under consideration. In Step 5, benefits for each county are also summed to obtain regional and national totals.

Sources of Uncertainty in the Benefit Calculations

Benefit analyses are subject to several sources of uncertainty, especially when human health effects are of interest. The major categories of uncertainty in this analysis concern:

- The scope and magnitude of air quality improvements likely under alternative standards.
- The evidence of the health and welfare effects of PM.
- The economic value of reduced adverse health risk.
- The coverage of potentially relevant effects/benefit categories.

Within each major category of uncertainty there are more specific problems of incomplete or conflicting data and analytic methods. For example, the air quality analysis uses county-wide linear rollback techniques. These techniques introduce a large element of uncertainty when estimating the air quality impacts of source emissions growth or specific control options. Similarly, the estimates of health effects are based on existing community health studies. All of these studies have limitations either in study design, data or analytic methods which limit the accuracy or reliability of the results.

Table 1-2 contains a more detailed list of selected major sources of uncertainty in this study. Items in the list are defined and discussed further later in this section or in other sections of the report. The other sections also contain more detailed lists.

For some of the items in Table 1-2, the degree of uncertainty is estimated quantitatively. For example, alternative benefit calculations can be carried out using: each available study, each available functional form implied by each study, upper- and lower-bound (i.e., $\pm 2\sigma$) coefficient estimates, alternative low-level concentrations, upper- and lower-bound health values, and alternative methods of aggregation. That is, an effort is made to identify the range of uncertainty present in the benefit estimates. The estimates of this range are explicitly reported. Sources of uncertainty that could not be quantified are described qualitatively in each report section.

One source of uncertainty that is particularly difficult to address is the variation in completeness of benefits/effects coverage among studies. This includes two problems. First, studies may provide overlapping coverage, in which case double counting of benefits may occur. This problem is addressed in the aggregation procedures discussed shortly. Second, studies may provide incomplete coverage, which would lead to under-counting benefits. As an example, this analysis includes very limited coverage of PM soiling in the industrial sector and excludes entirely the commercial, institutional, and governmental sectors.

It should also be noted that all of the studies used for estimating benefits are community studies as opposed to controlled laboratory experiments. As such, the results of these studies are generally in the form of identified statistical associations between PM concentrations and various

Table 1-2

SOURCES OF UNCERTAINTY IN THE BENEFIT CALCULATIONS

- Scope and Magnitude of Air Quality Improvements*
  - Use of county-wide rollback to predict air quality change at worst-case monitor.
  - Use of proportionality to predict change elsewhere in county.
  - Failure to account for potential air quality improvements resulting from emissions controls in adjacent counties.
  - Approximations required in converting among different PM measures (TSP, PM10, BS).
  - Use of 1977-78 as base year.

- Evidence of Health and Welfare Effects
  - Conflicting evidence across studies.
  - Incomplete control for confounding factors.
  - Use of study results from one time and area to estimate effects in another time and area.
  - No information on the size distribution of particles present during the studies.
  - Alternative functional forms possible.
  - Sampling variation in coefficient estimates.
  - Degree of risk at lower level PM concentrations.

- Valuation of Health Improvements
  - Inability to value some health changes.
  - Large variations in estimates of value assigned to mortality risk reductions.

- Coverage of Effects/Benefit Categories
  - Omission of potentially relevant categories.
  - Incomplete coverage within evaluated categories.
  - Possible overlap among certain categories.

* Note that uncertainty in the air quality estimates will affect both the cost and benefit calculations.

indicators of health or welfare status. Use of these statistical associations for benefit calculations requires the inference that the associations reflect cause-effect relationships. Such inferences are controversial because cause-effect relationships cannot be proven by statistical associations. Conclusions about causality are ultimately a matter of judgment, typically based on a consideration of such factors as the strength of the statistical association and its consistency and plausibility in comparison with other studies and facts. Consequently, the benefit analysis is careful to evaluate each group of studies on this basis. This evaluation is reflected in the subset of studies selected for benefit calculations and in the sensitivity analyses conducted on the results obtained.

SCENARIOS ANALYZED

Baseline Air Quality

The baseline for all scenarios is a projection of ambient air quality in each county for the period 1987 through 1995 (or 1989 to 1995). The baseline projection reflects the following major components: background ambient concentrations, area source emissions (e.g., roadway dust), emissions from current stationary sources and emissions from new stationary sources coming on-line during the period. Thus, ambient air quality in a county may improve or deteriorate in the baseline scenario, depending on the relative growth rates for area sources and new stationary sources and retirement/replacement rates for existing stationary sources.

In the baseline scenario, some pollution controls are assumed to be in place. In particular, unretired sources and one-half of any replacement sources are assumed to be controlled at 1978 control levels. The other replacement sources and all net new sources are assumed to be controlled at new source control levels. New source controls include BACT (Best Available Control Technology) which represents NSPS (New Source Performance Standards) and other new source control requirements. Further details concerning the baseline can be found in the cost analysis report (2).

The baseline scenario reflects some air quality improvement relative to the no-control situation. The alternative PM standards under consideration would represent an incremental improvement in air quality compared to the baseline scenario. For this reason, the benefits associated with the alternative PM standards are incremental benefits. These are the benefits estimated in this analysis. The total benefits of both baseline controls and the alternative PM standards are not estimated.

Alternative Standards

The various ambient standards considered in the benefit analysis are listed in Table 1-3. The standards are listed approximately in order of increasing stringency. The standards are distinguished by:

- Particle measure
  - PM10 (particles with an aerodynamic diameter less than or equal to a nominal 10 μm)
  - TSP (total suspended particulates, i.e., particles measured by the "hi-volume" sampler which collects particles of aerodynamic diameter of up to 25 to 45 μm.)
- Ambient concentration allowed
- Averaging time and distribution parameter
  - Annual, arithmetic mean
  - Annual, geometric mean
  - 24-hour, expected maximum value
  - 24-hour, one exceedance per year (i.e., second highest value)
- Implementation date
  - 1989 (all PM10 standards; some TSP standards)
  - 1987 (all other TSP standards)
- Attainment status
  - Scenario B (all counties attain the standard)
  - Scenario A (some counties remain in nonattainment).

Table 1-3

ALTERNATIVE AIR QUALITY STANDARDS

(in $\mu g/m^3$)

Pollutant	Annual Standard		24-Hour Standard		Implementation Date	Attainment Status
	Concentration	Parameter	Concentration	Parameter		
PM10	70	AAM	250	EMV	1989	A, B
PM10	55	AAM	--	EMV	1989	A, B
PM10	55	AAM	250	EMV	1989	A, B
PM10	55	AAM	200	EMV	1989	A, B
PM10	55	AAM	150	EMV	1989	A, B
PM10	48	AAM	183	EMV	1989	A, B
TSP	75	AGM	260	2nd High	1989	A, B
TSP	--	--	150	2nd High	1989	A, B
TSP	75	AGM	260	2nd High	1987	A, B
TSP	--	--	150	2nd High	1987	A, B

AAM = Annual arithmetic mean.
AGM = Annual geometric mean of all 24-hour average values.
EMV = Expected 2nd maximum value of all 24-hour average values.
2nd High = Second highest 24-hour average value observed per year.
A = Some counties experience non-attainment.
B = All counties attain and maintain the standard.

In both the cost and benefit analyses, pollution controls are assumed to be implemented at the beginning of the year (1987 or 1989). In the Scenario B cases, all counties are also assumed to achieve attainment of the standard at the beginning of the implementation year and to maintain the standard through the end of 1995. In the Scenario A cases, some counties may not be in attainment during some or all of the period. As indicated in the table, all standards were evaluated under both partial attainment (Scenario A) and complete attainment (Scenario B) conditions.

Several of the key concepts defined above can be illustrated graphically as shown in Figure 1-2. The upper curve in the figure represents the projection of baseline air quality. As noted previously, the baseline reflects sources and controls in place in 1978 plus growth and retirement/replacement of sources after that date. The dashed line represents the standard. The bottom curve identifies the improved air quality after implementation of additional controls in this case in 1989. Benefits are generated by the improvement in air quality indicated by the shaded area. Note that some improvement below the standard can occur. This results from approximations required in the cost analysis. Constraints are imposed to insure that the approximations do not result in predicted air quality improvements below background air quality levels.

Figure 1-2 illustrates the situation with complete attainment of the standard (type "B" scenarios). Figure 1-3 illustrates the case of partial attainment (type "A" scenarios). In this case, sufficient control options are not available to attain and maintain the standard throughout the applicable time period. As a result, both costs and benefits are lower than if complete attainment occurred.

As the previous figures indicate, benefits occur over a period of several years. It is thus convenient to express benefits in discounted present value terms. In calculating the discounted present value of benefits, the following conventions are employed:

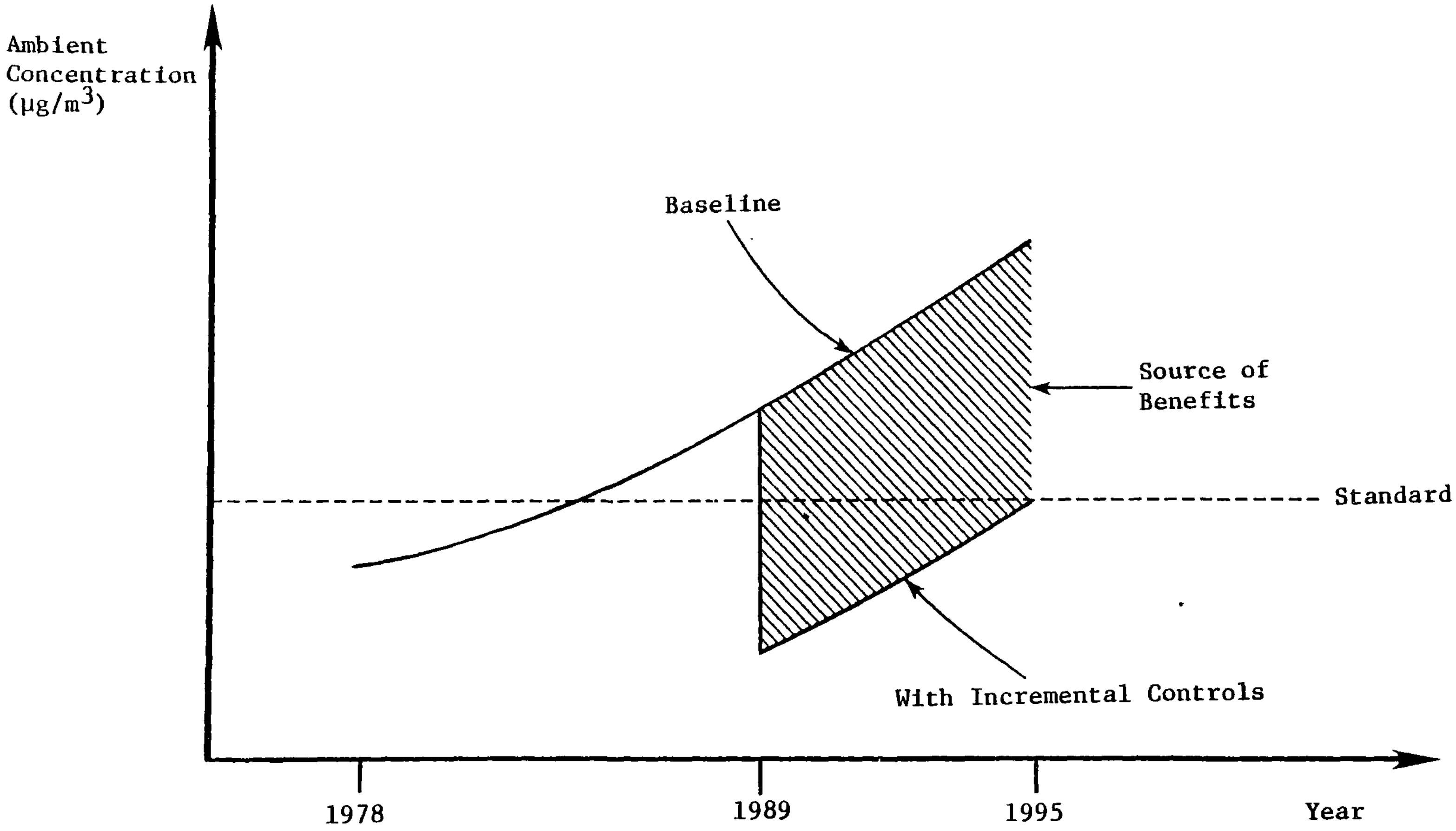

Figure 1-2. Typical Air Quality Scenario

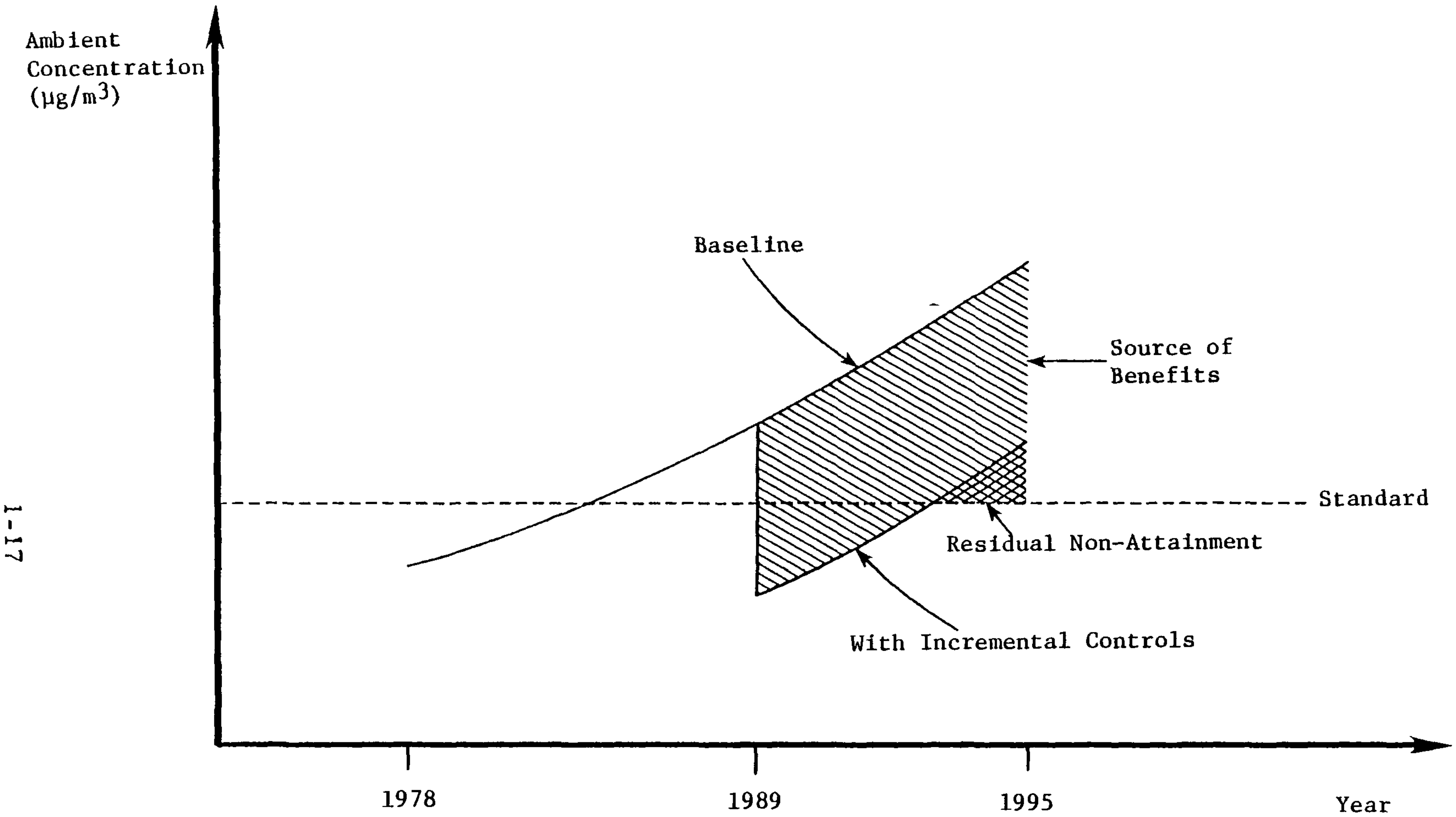

Figure 1-3. Residual Non-Attainment (Scenario "A")

- Time horizon corresponding to the standard (7 or 9 years).
- Present value as of January 1, 1982.
- Real discount rate of 10 percent.
- Estimates stated in 1980 dollars.
- Exclusion of benefits occurring after 1995.

INDEX OF EXPOSURE

The studies of the health and welfare effects of PM each employed specific indices of air pollution exposure. Many of the indices are different from those specified in the air quality standards under consideration. To use the results of these studies in a benefit analysis, the air quality estimates associated with the alternative TSP and PM10 standards must be converted to indices consistent with the studies. The studies used in the benefit analysis employed indices with the following characteristics:

- All studies used either an annual average concentration, a 24-hour average concentration, or a second-highest 24-hour average concentration per year.
- All but two studies used a TSP measure; the other two used British Smoke (BS) and Suspended Particulate Matter (SPM), respectively. None used a PM10 measure.
- The geographic areas included Census tracts, cities, counties and SMSAs (Standard Metropolitan Statistical Areas).
- The number of monitors in each area ranged from one to a dozen or more; in an area with multiple monitors, the original studies typically used the monitor recording the highest concentrations, or an average across monitors in the area.

Use of studies with the above characteristics is further complicated by limitations in the air quality data available from the cost analysis. The most important limitation is the lack of air quality data other than an estimate of the county maximum concentration in the baseline and post-control situations. The benefit analysis requires more complete data and must make additional approximations to supplement the data available. These approximations, and those associated with the index conversions described above, introduce another source of uncertainty in the benefit analysis. These issues are discussed in more detail in Sections 9 and 10, and to a lesser extent in the other report sections. The issues are summarized briefly here.

Averaging Times and Distribution Parameters

Ambient air quality data incorporating the required averaging times and distribution parameters are supplied from the cost and air quality analysis. The required averaging times include annual and 24-hour averages. The required distribution parameters include the arithmetic mean, geometric mean, and second-highest 24-hour concentration. The procedures employed to develop these data are described in the cost analysis report referenced earlier.

Particle Measures

To evaluate standards based on TSP, most of the studies are used directly since they were originally done in terms of TSP. The study based on SPM is also used directly based on the approximate equivalence of TSP and SPM measures. The study based on British smoke requires a specific transformation procedure from TSP to BS which is described in an appendix to Section 3.

For standards based on PM10, the cost and air quality analysis provides estimates of both the PM10 and TSP concentrations that result. The PM10 information cannot be used directly since none of the health or welfare studies used a PM10 measure. However, the availability of TSP concentration data makes it possible to estimate approximate benefits using the TSP studies (and the study requiring the TSP to BS transformation). This approach involves estimating the benefits of the TSP reduction that results when controls are applied to attain the PM10 standards.

Note that using TSP reductions to estimate the benefits of PM10 standards limits the comparisons possible between PM10 and TSP standards. Comparisons are possible only in terms of alternative levels of TSP stringency, not particle size. That is, the benefit analysis is not able to distinguish between a TSP standard and a PM10 standard that results in the same TSP reduction.

Evidence cited in the EPA/OAQPS Staff Paper indicates that smaller particles ($\leq$ 10 µm in diameter) pose a greater risk to the respiratory system than larger particles. Thus, the benefits of PM10 standards can be different than suggested by the benefits calculated from the associated TSP reduction. This could occur if the PM10 controls produce a proportionately different reduction in PM10 than in TSP.

The cost and air quality analysis provides estimates of the PM10 and TSP concentrations before and after implementation of controls. A review of these estimates for selected standards indicates that, in a majority of counties, PM10 does not decline proportionately more than TSP. This was found to be the case for both the PM10 and TSP standards examined.* This apparently results because control options available for PM10 in many cases also control larger particles as well. Hence, if emissions sources selected for control are producing both small and large particles, the proportionate reductions in PM10 and TSP may not differ appreciably.

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* The standards examined were the PM10 (70, 250), the PM10 (55, 150) and the 7-year TSP (75, 260). All were Scenario A (partial attainment) cases. All comparisons were before and after controls in 1989. All comparisons were between the PM10 annual arithmetic mean and the TSP annual arithmetic mean because the data available for the 24-hour averaging time were based on different statistical measures and cannot be directly compared. For all three standards, about 60 percent of the counties were predicted to experience a proportionately larger reduction in TSP; the other 40 percent experienced a proportionately larger reduction in PM10. About the same percentages were observed among the counties predicted to receive the largest benefits. In most of these counties, the predicted absolute change in the PM10 fraction was 0.01 to 0.03 under all three standards.

As indicated above, small differences are predicted between the PM10 standards and TSP standards analyzed, in terms of the resulting PM10 fractions. This implies that health benefits estimated based on the TSP change may be of similar accuracy for either type of standard. If the estimates are of similar accuracy, then it is appropriate in this study to draw comparisons between the PM10 and TSP standards. However, as noted previously, these represent comparisons of alternative levels of TSP stringency (i.e., alternative reductions in TSP). That is, the benefit analysis cannot distinguish among standards on the basis of particle size.

It is important to note that limitations and approximations required in the cost and air quality analysis make the estimates of the PM10 fraction in each county uncertain. Predicted baseline PM10 levels for each county in 1989-95 are based on an assumed PM10/TSP ratio of 0.55 in 1978, and predicted growth rates and small particle fractions for each emissions source category in the post-1978 period. Actual conditions may differ from these assumptions.* Furthermore, other factors, such as differences in small and large particle dispersion patterns, are not accounted for in the cost and air quality model, not thus in the benefit analysis. These uncertainties suggest that additional caution be used when comparing the benefit estimates for the PM10 and TSP standards.

__Geographic Areas and Monitor Types__

Ambient air quality data available from the cost analysis are estimates of conditions at the "design value" pollution monitoring site in each county. The design value monitor in a county typically is the monitor which recorded the highest ambient concentration (TSP annual mean or 24-hour second high) in 1977 and 1978. Concentrations at other monitors in the county are thus generally lower than at the design value monitor. Non-monitored areas in a county may experience higher or lower concentrations

* For example, more recent data indicates that in late 1981-early 1982 the PM10 fraction was closer to 0.46 on a national average basis (5). The PM15 fraction was closer to 0.55 at that time.

than the design value monitor, but lower concentrations are more likely. Air quality conditions at these other monitors and locations are not estimated in the cost analysis.* The cost and air quality analysis also omits the possibility of air quality improvements due to controls applied in an adjacent county.

Since projections of air quality and economic data are available primarily for county areas, the county is the basic unit of analysis in this study. This approach provides a good match with the original studies that used either county or SMSA data. The air quality change in the county is then taken to be either the change at the design value monitor, or the average change across all monitors in the county, depending on the measure used in the original study. When the average change is required, it is estimated from the design value monitor change by applying the proportionality factor which existed between these two values for each county in the 1978 base year. The proportionality factor on average was 0.74 for the annual mean and 0.70 for the 24-hour second-highest concentration.

Note that the above method for estimating the average air quality improvement across monitors in a county is only approximate. This is because the improvement at a particular monitor may or may not be proportional to the improvement at the design value monitor. That is, the dispersion properties of PM attenuate the air quality improvement occurring at various distances from the emissions sources being incrementally controlled. The proportionality assumption is an approximation to the actual attenuation. The degree of attenuation cannot be assessed without detailed dispersion modeling of the PM emission controls applied in each county. Such modeling is very time and resource intensive, and thus not practical in a nationwide study. As a result, the cost analysis relies on the more approximate county-wide rollback method for predicting air quality improvements at the design monitor in each county. County-wide rollback methods assume that the change in air quality (net of background concentra-

* For a small number of counties (12 out of 501), air quality is estimated for subcounty areas.

tions) at any location in a county is proportional to the change in total county emissions. Thus the use of proportionality in the benefit analysis to estimate the average air quality improvement across other monitors in a county is essentially a further application of county-wide rollback.

Lack of dispersion modeling also hinders use of studies which measured air quality effects at the city or Census tract level. For most appropriate use of the results of these studies, it would be desirable to have dispersion modeling results for subcounty areas. For example, for the same reasons noted previously, use of the air quality change projected at the county design value monitor may overstate the change which occurs elsewhere in the county. To provide a better air quality measure for these studies, the average air quality change across all monitors in a county is also used. The average change is more representative than the design monitor change. The average change is estimated as described previously.

Plausibility Checks

As noted above, the ideal situation would be to identify the change in PM concentration experienced by the population in each part of the county. In the absence of dispersion modeling results, the approximations described above attempt to improve upon the available concentration measure, the design monitor. Two plausibility checks were performed on these approximations. The first plausibility check concerned the use of the county average as an additional measure of the PM concentration. This check involved comparing the county averages in the 1978 base year with corresponding readings at monitors designated by EPA as "population-oriented" monitors. This analysis found that readings at population monitors are typically much closer to the county average than to the design value monitor readings.* This is not too surprising since 73 percent of all monitors in 1978 are designated as population-oriented. This suggests that

* The correlation between the average of all population monitors in a county and the average of all monitors in a county ranged between 0.95 and 0.96, depending on the averaging time. For population monitors and design values, the correlation ranged between 0.48 and 0.50.

the county average air quality is likely to be more representative than the design monitor as an estimate of the actual population exposure.

The second plausibility check concerned the accuracy of estimating the change in county average air quality based on a proportionality relationship to the change at the county design monitor. An analysis was undertaken to evaluate the quality of this approximation. The analysis, which is discussed further in Section 10, centers on the Chicago, Illinois area (Cook County). This area was chosen because it accounts for the largest fraction of total national benefits among all counties in the analysis and also had been the subject of detailed dispersion modeling previously. The analysis compares benefits estimated using two methods. First, benefits are calculated based on detailed dispersion modeling results for 31 subareas within Cook County. In the second method, dispersion modeling is used to predict the change at the design monitor only and proportional changes are assumed throughout the rest of the county. The second method, which is comparable to the approach used in the national benefit analysis, leads to estimates which are a factor of 2 to 4 higher than the first method. This suggests that the assumption of proportional air quality changes may introduce an upward bias in the national benefit analysis. However, there are a number of differences between the Chicago analysis and the national analysis which preclude an accurate estimate of the magnitude of the bias or its importance relative to other sources of upward and downward bias in the national analysis.

MEASUREMENT AND ECONOMIC VALUATION OF HEALTH IMPROVEMENTS

A companion study assesses the cost of pollution controls designed to attain alternative PM standards. Comparison of costs and benefits in commensurate terms requires placing an economic value on reductions in the risks of mortality and morbidity. Alternatives to a formal economic valuation process include choosing policy objectives which reduce all risk at whatever the cost, or which implicitly and sometimes unknowingly value reductions in risk. The alternative selected in this analysis is to explicitly value reductions in both mortality and morbidity risk. This allows the costs and benefits of the standards to be compared in commensurate terms.

Reduced Mortality Risk

The benefits of a reduction in mortality risk are evaluated based on a four-part calculation. The calculation is done for each geographic area. The four parts involve estimates of:

- The reduction in ambient PM concentration.
- The reduction in mortality risk corresponding to the reduction in ambient PM.
- The number of individuals experiencing the risk reduction (i.e., experiencing the PM reduction).
- The dollar value that one individual places on a unit reduction in mortality risk.

A hypothetical example will illustrate the four-part calculation. Suppose the annual mortality rate in an area is 15 deaths per 100,000 people. This may include deaths from a variety of causes as well as from air pollution. If we let r denote the annual mortality rate, then in this example r = 0.00015.

Another way to interpret r is as a probability. In this view, there is a 15 in 100,000 chance that an individual chosen at random will die during the year. That is, the representative individual faces a 0.00015 risk of mortality during the year.

Now suppose that epidemiology studies indicate that reducing air pollution by, say, 100 $\mu g/m^3$ annual average would cause r to decline by an amount Δr. For example, Δr might be 0.00001.* The question then is how to value this reduction in mortality risk.

In benefit analyses, the economic value of a small reduction in mortality risk is estimated by adding together the values that individuals assign to the reduction. Previous studies and surveys have developed estimates of individual values. These studies and surveys are reviewed in the Appendix to Volume II of this report. A typical approach is to observe the wage premiums associated with occupations involving differing degrees of mortality risk. The studies and surveys suggest that individuals are willing to pay about $1.00 per year for each reduction of 1×10^{-6} in annual mortality risk. For the previous example of a reduction $\Delta r = 0.00001 = 10 \times 10^{-6}$, the individual willingness to pay for this reduction is about $10.00 per year. This implies that a group of 100,000 individuals together would be willing to pay a total of (100,000)($10.00) = $1,000,000 if each experienced a risk reduction of 0.00001.

The actual values used in this benefit analysis for a unit reduction of 1×10^{-6} in annual mortality risk are:

- Minimum estimate: $0.36
- Point estimate: $1.58 (All in 1980 $)
- Maximum estimate: $2.80

This range reflects the different values implied by the studies and surveys reviewed in the Appendix to Volume II.

* The analysis can be made more exact by examining changes in mortality rates for various subgroups in the population (e.g., the elderly). However, this is appropriate only if specific subgroups were analyzed in the underlying research study that is used to estimate Δr.

Reduced Morbidity Risk

The benefits of a reduction in morbidity risk are estimated using a similar four-part calculation as in the case of mortality risk. In step two, however, the concern is with the reduction in morbidity risk per unit reduction in ambient PM; and in step four, the issue is one of valuing small changes in morbidity risk. The reductions in morbidity risk are estimated using results from previous epidemiology and economic studies. Valuation of morbidity risk is done taking into account three factors: the value of fewer expected work days lost due to illness; the value of fewer expected nonwork days with reduced activity levels due to illness; and the savings in expected medical expenditures. The method used to value each of these effects is identified below. The specific values vary from county to county.

Effect	Method of Valuation
Lost workday	Average daily wage
Reduced activity day	One-half of the average daily wage
Change in direct medical expenditures	Proportional to change in disease incidence

As discussed in the Appendix to Volume II, the above approach probably underestimates total willingness to pay for morbidity risk reductions because it excludes consideration of residual pain, suffering, and inconvenience.

Applicable Concentration Ranges for Concentration-Response Functions

The results of health effects studies can often be expressed in the form of concentration-response functions. Such functions represent a quantitative statement of the relationship between health status and ambient concentrations of an environmental pollutant such as particulate matter.* Concentration-response functions are useful in a benefit analysis because they provide a mathematical basis for calculating health improvements associated with air quality changes over different concentration ranges. This subsection is concerned with the ranges over which the concentration-response functions should be applied.

Concentration Ranges Suggested by CASAC and the EPA/OAQPS Staff Paper —

The EPA/OAQPS Staff Paper explicitly addressed the question of concentration ranges over which health effects may occur. The Staff Paper identified one set of ranges at or above which health effects are likely to occur among sensitive groups in the population; it identified a second, lower set of ranges over which effects may be possible, but for which the evidence and level of risk was less certain. These ranges were derived from the EPA Criteria Document and reflect consideration of the epidemiology studies judged to provide the most reliable quantitative evidence. The numerical values of these ranges are identified in Table 1-4.

EPA's Clean Air Scientific Advisory Committee (CASAC) also addressed the question of concentration ranges over which health effects may occur. Their conclusions were summarized in the CASAC Chairman's closure letter (6) on the Staff Paper. CASAC concluded that detectable health effects occur at the upper bound of the "Effects Possible" ranges identified in the Staff Paper. These ranges are 150 to 350 $\mu g/m^3$ for 24-hour PM10 concentrations (150 to 250 $\mu g/m^3$ BS) and 55 to 110 $\mu g/m^3$ for annual average PM10 concentrations (110 to 180 $\mu g/m^3$ TSP). The closure letter also made it clear that these conclusions were based solely on a review of currently available quantitative evidence from epidemiology studies. That is, CASAC did <u>not</u> say that there are no health effects at the lower end or below

* Following the practice of the EPA/OAQPS Staff Paper, this report uses the term "concentration-response function" when referring to community studies of ambient air pollution effects. The more traditional term "dose-response function" implies greater knowledge of actual exposure, as would be the case in a laboratory study.

Table 1-4

SUMMARY OF CONCENTRATION RANGES IN EPA/OAQPS STAFF PAPER*

	Short-Term		Long-Term	
	BS	PM10	TSP	PM10
"Effects Likely"	250-500	350-600	$\geq$ 180	90-110
"Effects Possible"	150-250	150-350	110-180	55-110

* All entries are in $\mu g/m^3$. Concentrations are given in both original study units and approximately equivalent PM10 units.

Source: EPA/OAQPS Staff Paper, op. cit., Tables 1 and 2.

these concentration ranges; it merely said that there was currently no quantitative evidence of effects.

Other Considerations in Selecting Concentration Ranges for the Benefit Analysis —

Some of the alternative PM standards under consideration may result in ambient PM concentrations below the lower bounds of the Effects Possible ranges identified by the Staff Paper. The lower bounds, 150 $\mu g/m^3$ for 24-hour PM10 (150 $\mu g/m^3$ BS) and 55 $\mu g/m^3$ for annual average PM10 (110 $\mu g/m^3$ TSP), will hereafter be referred to as the "Staff Paper lower bounds". As discussed in Sections 9 and 10, concentations below the Staff Paper lower bounds can result for several reasons. One example is that controls required in an area to attain a 24-hour standard may lead to associated reductions in annual average concentrations below the lower-bound annual concentration. The reverse can also happen. Sections 9 and 10 give additional examples.

The existence of air quality improvements below the Staff Paper lower bounds poses difficult problems for the benefit analysis. On the one hand, one can question the appropriateness of attributing benefits to air quality improvements below the Staff Paper lower bounds. The EPA staff has clearly given careful consideration to selection of the lower bounds. On the other hand, constraining the benefit calculations by the Staff Paper lower bounds also presents problems. The problems include: 1) the possibility that imposing the lower-bound constraints may introduce statistical bias in the benefit estimates; 2) the uncertainty concerning the existence of effects below the Staff Paper lower bounds; 3) data limitations which limit attention to the annual lower-bound concentration only; and 4) possible differences between the economic principles of benefit-cost analysis and the criteria used in selecting the "Effects Possible" range for standard setting purposes. These issues are discussed briefly below and further in Section 10.

Possible Statistical Bias — Practical constraints limit the benefit analysis to use of concentration-response functions which, in most cases, are taken directly from the original research studies. None of the studies used in the benefit analysis imposed the Staff Paper lower bounds at the time the concentration-response functions were statistically estimated, either by the authors or by Mathtech.* As discussed in Section 10, it is improper statistical procedure to impose a lower-bound constraint when calculating benefits unless it was also imposed or accounted for when the concentration-response function was originally developed. The impropriety most likely leads to downward-biased estimates of the level of benefits with the constraint imposed. That is, applying the constraint may lower benefits for two reasons — first, because benefits below the lower bound are truncated, and second, because the estimate of benefits above the lower bound may be downward biased.

Uncertainty About Lower-Bound Concentrations — As noted in the EPA Staff Paper (7), the available epidemiological data "do not ... show evidence of clear population thresholds but suggest a continuum of response

* Some of the studies discussed the issue of no-effects thresholds, but none accounted for such a possibility when estimating concentration-response functions.

with both the risk of effects occurring <u>and</u> the magnitude of any potential effect decreasing with concentration." This situation complicates any attempt to choose an "Effects Possible" concentration range. The fact that health effects exist on a continuum creates a difficulty in selecting the lower bound of the "Effects Possible" range. And the decreasing magnitude of any effects as concentrations decrease raises the question of whether particular effects are of sufficient health significance to influence choice of the range. Both of these factors combine to make selection of the lower bound subject to informed judgment as well as quantitative evidence.

The degree to which judgment must ultimately enter the decision is illustrated by the selection of the lower-bound annual concentration. The annual lower bound is based largely on a study of two Connecticut towns by Bouhuys, Beck and Schoenberg (8). The study found evidence of increased respiratory symptoms (cough, phlegm, and dyspnea) in the town with dirtier air (Ansonia), but no differences in prevalence rates for chronic bronchitis or lung function. Concentrations of TSP in the cleaner town averaged 40 $\mu g/m^3$ annual mean. Concentrations in Ansonia averaged 63 $\mu g/m^3$ annual mean during the year of the study, and up to 152 $\mu g/m^3$ annual mean during the previous seven years. The EPA Staff Paper characterizes pollution in Ansonia by a median value of 110 $\mu g/m^3$ TSP annual mean (9) and this value is the primary basis for the lower-bound annual concentration (10).*

Alternative conclusions are also possible from the Bouhuys <u>et al</u>. study. For example, the choice of 110 $\mu g/m^3$ out of the range 63 $\mu g/m^3$ to 152 $\mu g/m^3$ is not the only option. Furthermore, there is some possibility that any value in the 63-152 $\mu g/m^3$ range would not fully protect against increased respiratory symptoms. The presence of symptom differences between the two towns implies symptoms are produced at concentrations at least as low as in the dirtier town (63-152 $\mu g/m^3$) and possibly lower. Thus, a lower bound below 110 $\mu g/m^3$ might be necessary if it were desired

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* The EPA Staff Paper also cites studies by Ferris <u>et al</u>. (11-12) and Lunn <u>et al</u>. (13) as providing supporting evidence for this choice. See Section 10 for further discussion.

to protect against symptomatic effects with a margin of safety. This study thus points out the twin difficulties of selecting a lower bound and deciding on the health significance of observed effects.

An additional issue is the limited extent of the epidemiological data base available for the selection of critical concentration ranges. Only a few studies pass the CASAC tests of acceptability, and all of these studies have technical limitations of varying degrees. Consequently, as new studies become available, it is possible that they may point towards different conclusions. A case in point is Ostro's (14) recent reanalysis of the London mortality data that were the primary basis for the 24-hour lower bound identified by the Staff Paper. Ostro uses statistical methods to test formally for the existence of a threshold at various levels (the Staff Paper's analysis was informal). He finds very strong association between PM and mortality at concentrations below 200 $\mu g/m^3$ BS, strong association below 100 $\mu g/m^3$ BS, and some association below 75 $\mu g/m^3$ BS. Depending on the uncertain relationship between BS and PM10 at lower concentrations, these observed effects levels may be below the Staff Paper lower bound of 150 $\mu g/m^3$ PM10. However, Ostro's reanalysis was not available to CASAC or the EPA staff at the time they made their recommendations.

<u>Data Limitations</u> — The Staff Paper identified lower bounds for both 24-hour and annual mean concentrations. Application of these lower bounds requires pre-control and post-control air quality data on both a daily and annual basis. Air quality data available from the control cost and air quality analysis does not include daily data other than for the second-highest day per year. Thus, the benefit analysis can apply only the annual mean lower bound. The annual mean lower bound is directly applied to those benefit models using the annual mean as the pollution concentration index. As explained in Section 10, the annual mean lower bound can also be applied in the benefit calculations for the studies that originally used daily data. The 24-hour lower bound, however, cannot be applied.

Differing Objectives — The Criteria Document and Staff Paper provide a comprehensive discussion of PM-related health effects and the concentrations at which the effects appear. As the Staff Paper's use of the Bouhuys *et al*. study and others suggests, health effects of a significant or permanent nature are stressed when selecting the "Effects Possible" concentration range for the primary standard. Effects in the form of increased symptoms, by themselves, appear to be less influential in determining that range. Hence, there may be symptomatic effects occurring at concentrations below the Staff Paper lower bounds.

In contrast, the benefit analysis is concerned with the benefits of reducing ambient air pollution. Benefits are determined by individuals' willingness to pay for pollution reductions. Willingness to pay will be influenced by both risk assessment and risk valuation. Individuals may value a reduction in symptoms as well as valuing reductions in more significant health problems. Individuals may also have differing assessments of the health risks from PM. Either of these factors could lead to the existence of benefits at concentrations below the lower bounds selected during Staff Paper development. Thus, application of the Staff Paper lower bounds in the calculation of benefits may be inappropriate because of the differing objectives of benefit analysis compared to Staff Paper and Criteria Document development.

Benefit Calculations with Staff Paper Lower Bounds —

In view of the uncertainty about calculating benefits below the Staff Paper lower bounds, two sets of benefit estimates are provided in this report. One set is based on application of the concentration-response functions over nearly the full range of air quality improvements predicted for each county. Only two constraints are imposed in this first set of estimates: 1) limits implied by the range of PM concentrations present in the data of the original research studies; or 2) narrower limits if implied by the results of an individual study. The second set of benefit estimates has an additional constraint imposed. The second set excludes all health benefits predicted by the concentration-response functions at levels below the Staff Paper lower bounds. The summary sections of the report (Sections 1 and 2) provide highlights of both sets of results. Full details are provided in Section 11. However, the remaining sections of the report are concerned primarily with benefit calculations without the lower-bound constraints imposed.

SUMMARY OF RESULTS IN SPECIFIC BENEFIT CATEGORIES

Health Effects

This analysis considers six potential categories of health effects from particulate matter and other forms of air pollution: mortality effects due to either acute or chronic air pollution exposure, acute morbidity effects due to either acute or chronic exposure, and chronic morbidity effects due to either acute or chronic exposure.* The existing research base in each of these areas varies in scope and quality. In categories where there is some evidence of the relationships between particulate matter concentrations and rates of mortality and morbidity, estimates are made of the changes in mortality and morbidity risks associated with alternative standards. These risk reductions are then valued using the procedures described previously. The details of the procedures and results are described in Sections 3 and 4 of the report. An overview of the health results is provided below.

Economic Benefits of Health Improvements —

Table 1-5 summarizes the estimated economic benefits of health improvements associated with imposition of the PM10 (70, 250) Scenario B standard.** Estimates based on the epidemiology literature and the economic literature are separately identified. Note that neither

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* The terms acute exposure and chronic exposure are taken to be synonymous with the terms short-term exposure and long-term exposure, respectively.

** Estimates for the other standards are summarized in a later subsection. Table entries are displayed to the nearest $10 million. However, not all entries may be accurate to that many significant digits.

Table 1-5

INCREMENTAL HEALTH BENEFITS FOR THE PM10 (70, 250) SCENARIO B STANDARD*

Health Effect	Exposure	Epidemiology Literature			Economic Literature		
		Minimum	Point	Maximum	Minimum	Point	Maximum
Mortality	Acute	0.04	1.12	14.86	NA	NA	NA
	Chronic	NA	NA	NA	0	12.72	62.10
Morbidity (Acute)	Acute	0.15	1.32	11.91	NA	NA	NA
	Chronic	0	0	1.44	0.03	10.65	21.49
Morbidity (Chronic)	Acute	NA	NA	NA	NA	NA	NA
	Chronic	0.12	0.12	0.13	2.61	11.40	20.19

* 1982 discounted present values in billions of 1980 dollars for a 7-year time horizon (1989-95) and a 10 percent discount rate.

NA = No estimate available.

literature provides estimates in all six health-effect categories, but that five categories are covered by the two literatures taken together.

One of the largest benefit categories among the epidemiology-based estimates is the acute exposure mortality category. The mortality benefits are based on a study by Mazumdar et al. (15) of total mortality in London on a daily basis during 14 winters. Both PM (measured as British smoke) and SO_2 measurements were included in the study.

The three morbidity estimates from the epidemiology literature are based on studies by Samet et al. (16), Saric et al. (17), and Ferris et al. (18-20), respectively. These studies were concerned with acute or chronic respiratory disease. Because these studies do not clearly identify the relative importance of PM and SO_2, they may provide upward-biased estimates of PM related respiratory effects. On the other hand, the three morbidity estimates are also potentially downward biased due to the exclusion of nonrespiratory diseases and the conservative method for valuing morbidity effects.

The largest benefits among the economic literature estimates are in the chronic exposure mortality category. The estimates in this category are based on the results of nine separate studies. Most of the studies control for either SO_2 or SO_4 (a subset of PM), as well as PM. Six of the studies find associations between mortality and PM concentrations, while two find the SO_4 fraction of PM to be more influential.* One study finds little evidence of effects. This uncertainty is reflected in the minimum estimate of 0.0 for this category. The point estimate emphasizes the studies by Lave and Seskin (21) and by Lipfert (22-24), and uses results that are on the low end of the range of effects they observed.

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* Sulfates (SO_4) are primarily a constituent of the fine particle (approximately < 2.5 µm diameter) fraction of PM. As noted previously, it is difficult to predict whether and to what extent fine particle concentrations will be reduced by the control strategies required to attain the alternative PM standards under consideration.

Estimates for the chronic exposure acute morbidity category are based on studies by Ostro (25) and by Crocker et al. (26) which look at labor productivity effects (lost work days). The Ostro study also analyzes reduced activity days. These morbidity benefits may be underestimates because of the valuation method mentioned earlier. The first study controls for both PM and SO_4, while the other considers only PM in the final specification. Benefits in the chronic exposure-chronic morbidity category are based on a single study of labor productivity effects by Crocker et al. (27) which includes only PM in the final specification.

Range of Uncertainty —

The variation between the minimum and maximum estimates in Table 1-5 reflects several of the types of uncertainty present in the analysis. The general types of uncertainty were discussed previously. The epidemiology study of acute exposure mortality effects by Mazumdar et al. is illustrative of several specific examples. The variations in this instance reflect: 1) use of different functional forms for the dose-response function, both of which are consistent with the observed data; 2) use of the upper and lower bounds on the 95 percent confidence interval around the estimated coefficient for particulate matter in the concentration-response function; 3) use of coefficients estimated over different subsamples of the data; and 4) use of different estimates for the value of a marginal reduction in mortality risk. Note that other types of uncertainty are not reflected in the range. For example, not included are uncertainty about the air quality data and uncertainty introduced by using the results of a London study to evaluate U.S. conditions where particle composition and weather may differ.

The point estimate of benefits in the Mazumdar et al. example is obtained as follows. First, point estimates for the estimated coefficient and for the value of a marginal risk reduction are used to obtain new minimum and maximum benefit estimates based on the different functional forms and data subsamples. The new estimates have a smaller range, but one that still differs by an order of magnitude. The geometric mean of the new minimum and maximum values in each county is then calculated and summed over counties to obtain the U.S. total. The geometric mean is a natural measure of central tendency for numbers which differ by orders of magnitude.

Sensitivity to Staff Paper Lower Bounds —

As discussed previously, the EPA Staff Paper and the Clean Air Scientific Advisory Committee (CASAC) identified PM concentration ranges below which they concluded there was no quantitative evidence of health effects. These concentrations are 150 to 350 $\mu g/m^3$ for 24-hour PM10 and 55 to 110 $\mu g/m^3$ for annual average PM10 (110 to 180 $\mu g/m^3$ for annual average TSP). In theory, it is possible to calculate benefits under the assumption that no health benefits are produced by reducing PM below the lower bounds of these concentration ranges (the Staff Paper lower bounds). However, there are several practical problems with doing the calculation as part of this analysis. As discussed previously, these problems range from probable statistical bias to lack of daily data on PM concentrations. Subject to these previously discussed limitations, Table 1-6 contains the benefit estimates that result when all health benefits associated with reducing PM concentrations below 110 $\mu g/m^3$ annual average TSP are excluded. For comparison purposes, the table also includes the corresponding estimates when the lower-bound constraint is not applied. All estimates are point estimates for each category.

The estimates exhibit varying degrees of sensitivity to the Staff Paper lower bounds. The variations are due to differences in: 1) the index of PM exposure used; 2) the nonlinearity of the concentration-response function; and 3) other prior cutoffs imposed to provide consistency with the range of PM concentrations or effects found in the original studies. For the less stringent standards such as PM10 (70, 250), the chronic exposure mortality and morbidity estimates show little sensitivity to the lower bounds; they exhibit greater sensitivity with the more stringent standards.

Table 1-6

COMPARISON OF INCREMENTAL HEALTH BENEFITS FOR THE PM10 (70, 250) SCENARIO B STANDARD, WITH AND WITHOUT A LOWER BOUND APPLIED*

Health Effect	Exposure	Epidemiology Literature		Economic Literature	
		Lower Bound**	No Lower Bound	Lower Bound**	No Lower Bound
Mortality	Acute	0.31	1.12	NA	NA
	Chronic	NA	NA	11.98	12.72
Morbidity (Acute)	Acute	0.18	1.32	NA	NA
	Chronic	0	0	1.43	10.65
Morbidity (Chronic)	Acute	NA	NA	NA	NA
	Chronic	0.12	0.12	10.62	11.40

* 1982 discounted present values in billions of 1980 dollars for a 7-year time horizon (1989-95) and a 10 percent discount rate. Entries are point estimates for each category.

** Lower bound of 110 $\mu g/m^3$ TSP AAM applied.

NA = No estimate available.

Estimates of Physical Effects —

Implicit in the estimates of economic benefits are estimates of changes in health status. The changes in health status include reduced risk of mortality and morbidity. For economic valuation purposes, the consequences of reduced morbidity risk are further categorized into fewer work days lost, fewer reduced activity days, and reduced direct expenditures for medical care. For informational purposes, estimates for each of the physical effects categories are also developed. The estimates for each standard and scenario can be found in the supplementary tables in Section 11 of the report. The estimates are based on the same methods and data used in calculating economic benefits except that the final step of economic valuation is not performed.

Soiling and Materials Damage

Existing research on the soiling and materials effects of particulates has focused primarily on household soiling, and to a lesser extent on particle effects on paint, building stone and certain manufacturing industries. Benefits in this area are estimated using the results from a number of existing studies which are reviewed in Section 7. As suggested above, the existing literature to a large extent constrains the estimates to the benefits of reduced household soiling.

Table 1-7 presents estimates of the benefits of reduced household soiling with the PM10 (70,250) Scenario B standard. These estimates are based on three separate studies by Cummings et al. (28), Watson and Jaksch (29), and Mathtech (30). Highest weight is given to the Mathtech study, which had lower estimates than the other two. Also shown in Table 1-7 are estimated benefits of PM reductions in part of the manufacturing sector. These estimates are also based on a study by Mathtech (31). Only a few studies were identified concerning soiling effects in the commercial, governmental, or institutional sectors. Although these studies found no effects, the results may be unrepresentative because of limitations in study design. In view of the limited analysis of these other sectors and

Table 1-7

INCREMENTAL BENEFITS OF REDUCED SOILING FOR THE PM10 (70,250) SCENARIO B STANDARD*

	Minimum	Point	Maximum
Household Sector	0.73	3.14	13.85
Manufacturing Sector	0.73	1.30	9.45

* 1982 discounted present values in billions of 1980 dollars for a 7-year time horizon (1989-95) and a 10 percent discount rate.

the partial coverage of the manufacturing sector, the benefits of reduced soiling may be underestimated in this analysis.

Visibility and Aesthetics

Decreases in ambient concentrations of particulate matter may also generate benefits through improvements in visual range and the aesthetic quality of the environment. These benefits may accrue in several ways. For example, improvements in visiblity may enhance urban quality of life. They may lead to greater enjoyment of recreational activities. Furthermore, preservation of unique scenic vistas can lead to a type of benefit known as "existence value". Most visibility and aesthetic benefit studies rely on contingent valuation techniques which make use of specially designed surveys.

Visibility and aesthetic benefits associated with achieving alternative PM10 and TSP standards are not estimated in this analysis. However, contingent valuation studies have been used to develop point estimates of benefits associated with specified improvements in visual range (see Section 8). Use of those estimates in this analysis would require knowledge of the transformation between changes in PM10 or TSP and changes in visual range and plume blight. The transformation is complex with particle size being one of the more important factors. Fine particulates (i.e., those with diameters less than 2.5 μm) are more influential in determining visual range. Whether fine particulate concentrations are reduced markedly as a result of the alternative PM10 and TSP standards under consideration is a function of the control strategies employed. The EPA Staff Paper (32) suggests that the control strategies required may not appreciably reduce fine particulate concentrations and, hence, may not improve visual range. Changes in plume blight will also depend on the control strategies selected.

Property Value and Labor Market Studies

There are a variety of studies which indicate that some of the observed geographic variation in residential property values can be explained by site attributes including air quality. Therefore, it has been suggested that property value differentials attributable to air quality represent the capitalized market value of cleaner air. A smaller but comparable literature suggests the same phenomenon can be observed in the geographic variation in labor wage rates. Representative studies from these literatures are also used to develop benefits estimates (see Sections 5 and 6 for details). Note that these estimates are likely to reflect market perceptions of both health and welfare benefits of air quality improvements, and thus cannot be directly added to the health benefits described previously. However, they can provide an independent estimate of perceived health and welfare benefits. The property value and wage studies are used in this study to provide a cross-check on the health and welfare benefit estimates.

The benefits of the PM10 (70, 250) Scenario B standard as estimated from the property value and labor market studies are shown in Table 1-8. The estimate from the property value literature is based on about eight studies, most of which control for both PM and SO_2 or SO_4. The estimate from the labor market literature is based on two studies by Smith (33) and Rosen (34), both of which include only PM in their final specifications.

Table 1-8

INCREMENTAL HEALTH AND WELFARE BENEFITS FOR THE PM10 (70, 250) SCENARIO B STANDARD AS MEASURED FROM PROPERTY VALUE AND HEDONIC WAGE STUDIES*

	Minimum	Point	Maximum
Property Value Studies	3.43	6.85	11.42
Hedonic Wage Studies	9.81	19.81	37.21

* 1982 discounted present values in billions of 1980 dollars for a 7-year time horizon (1989-95) and a 10 percent discount rate.

The latter may be one explanation for why the labor studies provide higher estimates. However, another possibility is that the labor studies provide a more complete estimate of benefits.

AGGREGATE INCREMENTAL BENEFITS

Methods of Aggregation

The previous tables contain estimates of incremental benefits for a variety of benefit categories. The remaining task is to combine the estimates for the individual categories in order to develop an estimate of aggregate incremental benefits. Aggregate numbers are required in order for any benefit-cost analysis to proceed. However, aggregation cannot be accomplished by simply summing all of the categories because this might result in double counting and other problems.

Some of the issues which must be considered in choosing an aggregation procedure are:

- Does the procedure give due consideration to the relative strength of the evidence across different benefit categories?

Table 1-9

ALTERNATIVE AGGREGATION PROCEDURES

Benefit Category	Procedure					
	A	B	C	D	E	F
Mortality	Mazumdar et al.	Mazumdar et al.	Mazumdar et al.	Lave & Seskin; Lipfert	Lave & Seskin; Lipfert	Col. C + Col. D
Acute Morbidity	--	Samet et al.	Ostro	Ostro	Ostro	Col. B + Col. C
Chronic Morbidity	Ferris et al.	Ferris et al.	Ferris et al.	Ferris et al.	Crocker et al.	Crocker et al.
Household Sector Soiling & Materials	--	--	Mathtech	Mathtech	Geom. mean of Cols. D & F at county level	Watson & Jaksch + Cummings et al.
Manufacturing Sector Soiling & Materials	--	--	--	--	Mathtech	Mathtech
Other Sectors Soiling & Materials	--	--	--	--	--	--

- Does the procedure avoid double counting of benefits?
- Does the procedure provide complete coverage of benefits?

Since no one procedure best satisfies all three criteria, it is useful to consider various alternative approaches. Six possible alternatives are identified in Table 1-9. They give differing weights to the three criteria. Each alternative is discussed further below and in Section 10.

Procedure A —

Aggregation Procedure A is designed to be consistent with the CASAC's review of the scientific literature. In the Criteria Document for PM and SO_x, CASAC distinguished between studies providing quantitative evidence of pollution-related effects and those providing less quantitative evidence. Among the health studies considered adaptable for use in this benefit analysis, the studies by Mazumdar et al. and Ferris et al. were judged by CASAC to be in the quantitative category (35). Procedure A includes only these two health studies. (Other studies were judged by CASAC as providing quantitative evidence, but they could not be adapted for benefit calculations.)

Procedure A also excludes all non-health studies. The Criteria Document acknowledges the probable existence of non-health effects such as soiling (36), but is noncommittal regarding the availability of quantitative evidence for such effects.

It is unlikely that Procedure A involves any double counting of benefits. This conclusion follows because of its incomplete coverage of benefit categories.

Procedure B —

This procedure is similar to the previous one with the exception that the health study by Samet et al. has been included. This modification is consistent with the conclusions of the EPA Staff Paper (37) concerning studies providing reasonable evidence of concentration-response relationships for health effects. The Staff Paper includes the Samet et al. study in this category, as well as the studies in Procedure A.

As with Procedure A, no non-health studies are included. The Staff Paper, like the Criteria Document, is noncommittal regarding the availability of quantitative non-health effects evidence.

Procedures C Through F —

The studies included in Procedures A and B are among those judged by CASAC and the EPA Staff Paper as providing the most reliable quantitative evidence of air pollution effects. Procedures C, D, E, and F make increasing degrees of use of other studies. This includes studies such as the one by Ostro which had not yet been formally published prior to closure of the Criteria Document. It also includes studies that CASAC judged to be less reliable but that still have some merit. With these latter studies, it is of interest to trace out their implications. Even though these studies were judged less reliable, they provide the only available evidence of the potential magnitude of benefits in some categories (e.g., chronic exposure mortality). Including calculations based on these studies provides greater assurance that potentially important effects of PM have not been omitted from the benefit analysis. At the same time, the distinction is maintained between these studies and the CASAC-approved studies by including them in different aggregation procedures.

Procedures C through F differ in the degree to which the additional studies are used (C is more selective). The procedures also differ in the importance assigned to avoidance of double counting versus completeness of coverage (C stresses avoidance of double counting).

Procedure C —

Procedure C brings in the study of acute morbidity by Ostro. This recent study is not cited in the Criteria Document and, in fact, the benefit analysis uses later, supplemental results not available prior to the Criteria Document final draft.

Among the available health studies not already included in Procedures A and B, the Ostro study is rated very high for purposes of an economic benefit analysis. The Ostro study has several features which, taken together, lead to this conclusion. First, the study uses data on individuals (microdata) rather than macrodata such as vital statistics. Microdata are preferred because they improve the accuracy of the estimates of the dose-response function parameters and enable more direct application of proper statistical controls. Second, the study uses data samples from 90 medium-sized U.S. cities. The broad scope of the sample provides greater assurance that the estimates of health effects can be used as the basis for a national benefit analysis. Third, in identifying the pollution exposure for each individual, the study locates individuals by city of residence rather than by county or SMSA. It also uses an average of the readings among the population-oriented monitors in each city rather than using a single monitor or worst-case monitor. Fourth, the study controls for smoking habits as well as a variety of other economic and demographic variables. While the study does have some limitations (e.g., no control for dietary habits, limited control for occupational hazards and exposure), its other features make it clearly superior for use in a benefit analysis.

With the addition of the Ostro study in Procedure C, the study by Samet _et al_. is omitted to avoid possible double counting of benefits. The Samet _et al_. study is concerned with acute respiratory effects, which may be a subset of the effects captured in the Ostro study. The Ostro study is also given preference over the acute morbidity study by Saric _et al_. The latter study provides less complete coverage of diseases (respiratory disease only) and limited concentration-response information (e.g., no separation of PM/SO_2 effects, no information on PM effects below 200 $\mu g/m^3$ annual mean, etc.).

Procedure C also incorporates the Mathtech study of household soiling effects. The Criteria Document and Staff Paper reference this recent study but are noncommittal as to its use for quantitative purposes. The study is included here in order to provide some coverage of soiling effects, in recognition of its strong analytical features, and because of the favorable peer review which the study has received.

Note that Procedure C excludes possible chronic exposure mortality effects, provides limited coverage of chronic morbidity effects (respiratory illness only), and offers limited coverage of soiling effects.

Procedure D —

Procedure D addresses some of the possible incompleteness of coverage present with Procedure C. In particular, Procedure C omits the possibility of benefits from reduced mortality risk due to long-term exposure. There are many existing, cross-sectional studies of long-term exposure mortality effects. The majority conclude that mortality effects exist. However, these studies are not highly regarded by CASAC, so care is taken in how the results of these studies are used in the benefit analysis. This includes carefully assessing the limitations of each study and ultimately using results which are at the low end of the studies finding effects.

Summarizing briefly, nine chronic exposure mortality studies are reviewed in detail in Section 4 of the report. As noted previously, six of those studies found statistically significant associations between mortality rates and PM (generally measured as TSP). Two others found that it was the sulfate component of PM, rather than TSP, that had an association. The ninth found little evidence of association between mortality and air pollution.

The three studies finding no PM effects have been faulted for inclusion of an excessive number of pollution variables and/or control variables. This leads to multicollinearity and reduces the possibility of finding statistically significant PM effects. At least one of the three no-effect studies also used relatively more recent data when mean levels of TSP were reduced compared to earlier years, thus reducing the possibility of finding significant effects. These negative results (no effects = no benefits) are nonetheless retained for use as a lower-bound estimate of zero for this category.

The six positive-effect studies (and the no-effect studies) have been faulted on other grounds. Some have used relatively aggregate data. Some have been criticized for the pollution monitoring used. All of the studies have incomplete statistical controls, which is also true of the studies included in Procedures A through C.

Particular attention in the benefit analysis is focused on the mortality studies by Lave and Seskin and more recent studies which have attempted to address the criticisms of their work. Two studies by Lipfert are important in this regard. In one study, Lipfert used SMSA mortality data and air pollution data, as done earlier by Lave and Seskin. He found results comparable to those of Lave and Seskin and comparable to those obtained in his parallel analysis using less aggregate data at the city level. In a second study, Lipfert did a reanalysis of the Lave and Seskin work and added an approximate control for smoking. This study also found results consistent with Lave and Seskin's original results. Based on these findings, the benefit analysis uses results which are on the low end of the range observed by Lipfert and Lave and Seskin. These results are also considerably lower than those found in two of the three other studies finding positive effects. Thus, the point estimate of chronic exposure mortality benefits included in Procedure D is based on the low side of the evidence available among studies finding chronic exposure effects.

With the addition of the chronic exposure studies, the acute exposure study by Mazumdar et al. is dropped from this procedure. This is because of the possibility for overlap between these estimates. In particular, the chronic exposure studies are based on annual mortality rates. Annual mortality rates will include all deaths during the year, including those deaths that may be due to acute exposures. Thus, it is possible for the chronic exposure studies to be capturing the mortality effects of both acute and chronic exposure. The extent to which this may happen is unknown, however. It depends on a variety of factors such as the functional forms for the acute and chronic dose-response relationships, the statistical correlation between the measures of acute and chronic exposure, and so on. To be conservative in the estimate of benefits, the acute exposure study is eliminated from this procedure.

Procedures E and F —

Procedures E and F are most easily considered together. Procedure E addresses the incomplete coverage of the chronic morbidity category and the underestimation of soiling effects. In Procedures A through D, chronic morbidity estimates are based on the study by Ferris et al. which includes only respiratory diseases. In Procedure E, the Ferris et al. study is replaced by the Crocker et al. study which includes more chronic illnesses.

In Procedure E, the Mathtech study of soiling and materials damage in parts of the manufacturing sector is included. The coverage of household sector soiling is also expanded. The latter is done by taking into consideration the results of studies by Watson and Jaksch and by Cummings et al. The sum of these two studies is used in Procedure F, in view of the possibility that together they may overestimate benefits. In contrast, the Mathtech household study probably underestimates benefits. Procedure E thus uses a compromise estimate for household soiling: the geometric mean of the Mathtech estimate and the sum of the estimates based on Cummings et al. and Watson and Jaksch. The geometric mean is used as a conservative measure of the average of the two estimates.

The remainder of the estimates used in Procedure F also seek to provide more complete coverage of benefits, with the possible risk of some double counting. In particular, the benefits for the acute and chronic exposure studies for mortality are added together; the same is also done with the estimates from the acute and chronic exposure studies of acute morbidity. As a result, Procedure F provides the most complete estimate of benefits possible with the available studies. However, it may involve some double counting. The possibility of double counting is less likely to arise with any of the procedures A through E.

Results of the Aggregation Procedures

Applying the procedures outlined in Table 1-9 leads to the results shown in Table 1-10. The benefit estimates shown in the table are for the PM10 (70, 250) Scenario B standard. The estimates for Subtotal 2 range from a low of $1.24 billion for Procedure A to $52.4 billion for Procedure F. Most of the variation is due to the differing estimates of health benefits. Benefits of reduced mortality risk are estimated to range from $1.1 billion to $13.8 billion. For acute morbidity, the range is $0 to $12.0 billion. For chronic morbidity, the estimates range from $0.12 billion to $11.4 billion.

The range of values between Procedures A and F results from the alternative ways to combine the various studies and benefit categories. It does not reflect the uncertainty present in the estimates for the individual studies. That is, all entries in the table are based on the point estimate for each study or benefit category. If the additional uncertainty about each study were incorporated, as reported previously in Tables 1-5 and 1-7, the full range of variation in Subtotal 2 would be $160 million to $146 billion. These broader estimates of the range of uncertainty for each standard are reported in the tables contained in Section 11.

Note that the table makes a distinction between Subtotals 1 and 2. Subtotal 2 includes both manufacturing sector benefits and benefits accruing to individuals and households (Subtotal 1). The distinction between the two subtotals enables comparisons to be made with the estimates from the property value and hedonic wage studies.

The benefit estimates based on the property value and hedonic wage studies are shown at the bottom of Table 1-10. These estimates are the same as reported previously in Table 1-8. They are not included in the subtotals because they are believed to have substantial overlap with the

Table 1-10

INCREMENTAL BENEFITS FOR THE PM10 (70, 250) SCENARIO B STANDARD*

Benefit Category	A	B	C	D	E	F
Mortality	1.12	1.12	1.12	12.72	12.72	13.84
Acute Morbidity	0.0	1.32	10.65	10.65	10.65	11.97
Chronic Morbidity	0.12	0.12	0.12	0.12	11.40	11.40
Household Sector Soiling & Materials	0.0	0.0	0.73	0.73	3.14	13.85
Subtotal 1	1.24	2.56	12.63	24.24	37.92	51.07
Manufacturing Sector Soiling & Materials	0.0	0.0	0.0	0.0	1.30	1.30
Subtotal 2	1.24	2.56	12.63	24.24	39.22	52.36
	Minimum		Midpoint		Maximum	
Property Value Studies	3.43		6.85		11.42	
Hedonic Wage Studies	9.81		19.81		37.21	

* 1982 discounted present values in billions of 1980 dollars for a 7-year time horizon (1989-95) and a 10 percent discount rate. Individual entries may not sum to subtotals due to independent rounding.

benefit categories included in Subtotal 1 (health, household soiling, and visibility benefits). Rather, they are reported here to serve as a cross-check on the benefit numbers estimated from the health and welfare effects studies. Note that the range of property value estimates falls between the totals for Procedures B and C. The range of wage estimates encompasses Procedures C and D.

Unfortunately, the exact relationship between benefits included in Subtotal 1, and benefits estimated from property value and wage (PV&W) studies is unknown. However, several general points can be made. First, PV&W studies are behavioral studies. That is, they record how individuals respond to external factors such as market prices, housing (or job) characteristics, and amenities such as air quality. This implies that benefit estimates from PV&W studies will depend on: 1) individuals' perception of air quality; 2) individuals' perception of how air quality affects health, household soiling, etc.; and 3) how individuals respond to these perceptions. This means that PV&W studies can account for individuals' efforts to avert or mitigate the effects of air pollution.

In contrast to PV&W studies, most of the health studies used in this report do not account for averting or mitigating behavior. Rather, the central issue is one of identifying the technical relationship between health status and air quality. If averting or mitigating behavior has occurred prior to conducting a health study, then health effects will be reduced and the study's estimate of effects will be understated.

At the same time, the dependence of PV&W studies on perception and behavioral adjustments can lead PV&W studies to underestimate the benefits of air pollution reductions. For example, if there are air pollution health effects which individuals do not perceive, PV&W studies will not identify these effects.

The possibility of unperceived health effects suggests that PV&W studies should be viewed as lower-bound estimates of aggregate benefits. In this view, the property value estimates suggest that aggregation procedures A, B, and possibly C provide underestimates. The wage studies suggest that A, B, C, and possibly D are too low. The PV&W results are thus consistent with the earlier observations that Procedures A through D probably provide incomplete coverage of benefits.

The relationship between the estimates from PV&W studies is also not well understood. The wage studies used for the benefit estimates are both specified in terms of the "real" wage. The real wage is calculated by dividing the nominal (actual) wage by a cost-of-living index, one component of which is the cost of housing. Thus, benefit estimates based on the real wage models may reflect adjustments to air pollution in both the labor and property markets. This suggests that the benefit estimates from real wage models may be inclusive of benefits estimated from property value models. It also may explain why the benefit estimates are larger with the wage models than the property value models ($19.81 billion vs. $6.85 billion).

Incremental Benefits for Other Standards and Scenarios

Alternative Standards —

The previous discussion has focused entirely on the PM10 (70, 250) Scenario B standard. Incremental benefits for a variety of alternative standards considered in this analysis are shown in Table 1-11. The alternatives include all of the standards defined previously in Table 1-3. They include six PM10 standards with 1989 implementation dates, two TSP standards with 1989 implementation dates, and two TSP standards with 1987 implementation dates. All standards extend through 1995. All estimates are displayed to two significant digits.

As noted previously, health studies available for the benefit analysis do not incorporate particle size information. Benefits shown in the table for the PM10 standards are based on the TSP change that results. Comparisons across PM10 and TSP standards thus reflect only differences in relative stringency in terms of the TSP reduction; they do not reflect differences in particle size. If PM10 standards lead to proportionately

Table 1-11

INCREMENTAL BENEFITS FOR ALTERNATIVE PM10 AND TSP STANDARDS*
(B Scenarios)

Alternative Standard	Aggregation Procedure					
	A	B	C	D	E	F
PM10 70 AAM/250 24-hr. 7 yr.	1.2	2.6	13	24	39	52
PM10 55 AAM/- 7 yr.	1.8	4.1	22	43	74	98
PM10 55 AAM/250 24-hr. 7 yr.	1.8	4.2	22	43	74	98
PM10 55 AAM/200 24-hr. 7 yr.	1.8	4.3	23	44	76	100
PM10 55 AAM/150 24-hr. 7 yr.	2.0	5.0	27	52	90	120
PM10 48 AAM/183 24-hr. 7 yr.	2.1	5.2	29	56	98	130
TSP 75 AGM/260 24-hr. 7 yr.	2.1	5.2	29	57	100	130
TSP -/150 24-hr. 7 yr.	2.4	6.4	36	71	120	160
TSP 75 AGM/260 24-hr. 9 yr.	2.9	7.2	41	81	140	190
TSP -/150 24-hr. 9 yr.	3.3	8.9	50	100	170	230

* 1982 discounted present values in billions of 1980 dollars at a 10 percent discount rate. The 7-year time horizon is 1989-95 and the 9-year horizon is 1987-95. Comparisons between PM10 and TSP standards are in terms of TSP stringency, not particle size.

larger reductions in PM10 relative to TSP, benefits for the PM10 standards may be underestimated. Data from the cost and air quality analysis suggest that proportionately larger reductions do not generally occur. However, approximations in that analysis are such that the comparisons should still be interpreted with caution. This is signified by the line in the table separating the two groups of standards.

The standards are listed in approximate order of increasing stringency with the PM10 (70, 250) as the least stringent and the TSP (-, 150) as the most stringent. The ordering is only approximate for two reasons. First, the ordering is different depending on whether the annual or 24-hour concentration is used. Second, the PM10 and TSP standards use different statistical measures. The PM10 standards are stated in terms of arithmetic means, expected second maximum values, and particles less than or equal to 10 μm in diameter; the TSP standards use geometric means, observed second highest values and total suspended particles. This means that relative stringency will vary from county to county, depending on the particle size distribution and the temporal distribution of air quality in each county.*

An examination of Table 1-11 reveals several general patterns. First, incremental benefits increase as the stringency of the standard increases. This results because more stringent standards lead to larger improvements in air quality, and also increase the number of counties where air quality improvements occur. Second, the ordering of standards in terms of incremental benefits is insensitive to the choice of a particular aggregation procedure. That is, the ordering is the same for all six procedures. Third, standards with earlier implementation dates produce larger incremental benefits. This is also to be expected since earlier implementation leads to improvements in air quality which are earlier and of longer duration.

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* As an example, it is possible for air quality in one county to have a larger annual geometric mean and a smaller annual arithmetic mean than in another county. In this case, it would be possible for a geometric mean standard to be binding in the first county but not binding in the second and vice versa for an arithmetic mean standard. The same is true for comparisons between different monitors.

It should be noted that large benefits for a particular standard do not necessarily imply that the standard is economically preferable to some other standard with lower benefits. The costs of attaining the standard must also be considered. This is done in Section 2 of this report.

A Scenarios —

Table 1-12 contains estimates of the same ten alternative standards for the "A" scenario case. Recall that the A scenarios include some counties where available control options are insufficient to attain the standards. In the B scenarios, these counties are forced into attainment. The degree of air quality improvement is thus lower in the A scenarios relative to the corresponding standards in the B scenarios. Hence, benefits (and costs) are also lower with the A scenarios.

The A scenario results exhibit the same general patterns as the B scenarios. Benefits are larger with more stringent standards and with earlier implementation dates, and these patterns exist for all six aggregation procedures. As with the B scenarios, costs of control associated with each standard must also be considered before drawing conclusions about the economic attractiveness of a particular standard.

Sensitivity to Staff Paper Lower Bounds —

As discussed previously, it is of interest to calculate benefits under the assumption that no health benefits are produced by reducing PM below the Staff Paper lower bounds of 55 $\mu g/m^3$ annual PM10 (110 $\mu g/m^3$ annual TSP) and 150 $\mu g/m^3$ for 24-hour PM10. As also discussed previously, there are several practical problems with doing the calculation, ranging from probable statistical bias to lack of daily data on PM concentrations. Subject to these previously discussed limitations, Tables 1-13 and 1-14 contain the benefit estimates that result when all health benefits associated with reducing PM concentrations below 110 $\mu g/m^3$ annual average TSP are excluded. Table 1-13 provides results for the B scenarios while Table 1-14 incorporates the A scenarios.

Table 1-12

INCREMENTAL BENEFITS FOR ALTERNATIVE PM10 AND TSP STANDARDS*
(A Scenarios)

Alternative Standard	Aggregation Procedure					
	A	B	C	D	E	F
PM10 70 AAM/250 24-hr. 7 yr.	0.88	1.7	8.2	16	24	32
PM10 55 AAM/- 7 yr.	1.1	2.3	11	22	35	47
PM10 55 AAM/250 24-hr. 7 yr.	1.1	2.3	11	22	35	47
PM10 55 AAM/200 24-hr. 7 yr.	1.1	2.4	12	23	36	49
PM10 55 AAM/150 24-hr. 7 yr.	1.2	2.7	14	26	43	58
PM10 48 AAM/183 24-hr. 7 yr.	1.2	2.8	14	27	43	59
TSP 75 AGM/260 24-hr. 7 yr.	1.2	2.8	14	27	44	60
TSP -/150 24-hr. 7 yr.	1.4	3.4	18	34	56	76
TSP 75 AGM/260 24-hr. 9 yr.	1.7	3.9	20	38	62	84
TSP -/150 24-hr. 9 yr.	1.9	4.7	25	48	78	110

* 1982 discounted present values in billions of 1980 dollars at a 10 percent discount rate. The 7-year time horizon is 1989-95 and the 9-year horizon is 1987-95. Comparisons between PM10 and TSP standards are in terms of TSP stringency, not particle size.

Table 1-13

INCREMENTAL BENEFITS FOR ALTERNATIVE PM10 AND TSP STANDARDS, WITH LOWER BOUND APPLIED*
(B Scenarios)

Alternative Standard	Aggregation Procedure					
	A	B	C	D	E	F
PM10 70 AAM/250 24-hr. 7 yr.	0.44	0.62	2.6	14	28	40
PM10 55 AAM/- 7 yr.	0.46	0.66	3.3	19	41	61
PM10 55 AAM/250 24-hr. 7 yr.	0.46	0.66	3.3	19	41	61
PM10 55 AAM/200 24-hr. 7 yr.	0.46	0.66	3.4	19	41	62
PM10 55 AAM/150 24-hr. 7 yr.	0.46	0.66	3.7	19	42	69
PM10 48 AAM/183 24-hr. 7 yr.	0.46	0.66	3.8	19	43	71
TSP 75 AGM/260 24-hr. 7 yr.	0.46	0.66	3.8	19	43	71
TSP -/150 24-hr. 7 yr.	0.46	0.66	4.3	19	47	84
TSP 75 AGM/260 24-hr. 9 yr.	0.57	0.82	5.0	26	60	100
TSP -/150 24-hr. 9 yr.	0.58	0.82	5.7	27	64	120

* With TSPAAM lower bound of 110 $\mu g/m^3$ applied to all health studies. 1982 discounted present values in billions of 1980 dollars. Comparisons between PM10 and TSP standards are in terms of TSP stringency, not particle size.

Table 1-14

INCREMENTAL BENEFITS FOR ALTERNATIVE PM10 AND TSP STANDARDS, WITH LOWER BOUND APPLIED*
(A Scenarios)

Alternative Standard	Aggregation Procedure					
	A	B	C	D	E	F
PM10 70 AAM/250 24-hr. 7 yr.	0.34	0.47	1.8	9.4	17	24
PM10 55 AAM/- 7 yr.	0.34	0.47	2.0	11	20	31
PM10 55 AAM/250 24-hr. 7 yr.	0.34	0.47	2.0	11	20	31
PM10 55 AAM/200 24-hr. 7 yr.	0.34	0.47	2.0	11	21	31
PM10 55 AAM/150 24-hr. 7 yr.	0.34	0.47	2.1	11	22	35
PM10 48 AAM/183 24-hr. 7 yr.	0.34	0.47	2.1	11	21	35
TSP 75 AGM/260 24-hr. 7 yr.	0.34	0.47	2.1	11	21	35
TSP -/150 24-hr. 7 yr.	0.34	0.47	2.4	11	23	41
TSP 75 AGM/260 24-hr. 9 yr.	0.44	0.60	2.9	15	30	49
TSP -/150 24-hr. 9 yr.	0.44	0.60	3.2	16	33	58

* With TSPAAM lower bound of 110 $\mu g/m^3$ applied to all health studies. 1982 discounted present values in billions of 1980 dollars. Comparisons between PM10 and TSP standards are in terms of TSP stringency, not particle size.

The effect of imposing the Staff Paper lower bound is to reduce the benefits associated with all of the standards. It reduces the more stringent standards proportionately more than the less stringent standards. This results because the more stringent standards produce air quality improvements which are increasingly below the lower bound concentration. Hence, benefits show little increase since no credit is taken for below-lower bound air quality improvements.

Geographic Distribution of Benefits

Benefits of reduced PM concentrations vary considerably among the different regions of the country. This is the result of several factors such as differences in baseline air quality, differences in population, and differences in population growth rates. As an illustration, regional benefits for the PM10 (70, 250) Scenario B standard are shown in Table 1-15. The benefits are in discounted present value terms and the regions shown are the standard Federal administrative regions. As can be seen, nine of the ten regions receive benefits (the exception is New England). Particularly large shares of the benefits arise in Regions V (East North Central), VI (South Central), and IX (South Pacific). These shares change depending on the particular aggregation procedure used (A through F). For example, Procedure A suggests that 54 percent of the benefits would occur in Region IX. Under Procedure E, the estimate for Region IX falls to 32 percent and is exceeded by the 35 percent share in Region V.

Analysis of the other standards indicates that regional shares also change depending on the standard under consideration. For example, the PM10 (70, 250) Scenario B standard is the only one in which Region I (New England) receives no benefits. For all other B scenario standards, Region I receives positive benefits under all aggregation procedures, and the same pattern occurs with the A scenarios (assuming no lower bound constraint is imposed). A general observation is that benefits are more widely shared with the more stringent standards. This results in large part because more counties would be in non-attainment with the more stringent standards and thus more counties would experience an air quality improvement over

Table 1-15

INCREMENTAL BENEFITS BY REGION FOR THE PM10 (70, 250) SCENARIO B STANDARD*

EPA Region	Aggregation Procedure					
	A	B	C	D	E	F
I New England	0.0	0.0	0.0	0.0	0.0	0.0
II New York-New Jersey	0.0	0.00	0.02	0.04	0.06	0.08
III Middle Atlantic	0.08	0.14	0.64	1.08	1.88	2.51
IV South Atlantic	0.05	0.13	0.70	1.34	2.20	2.94
V East North Central	0.23	0.63	3.69	8.36	13.68	17.57
VI South Central	0.08	0.24	1.38	2.89	4.60	6.15
VII Midwest	0.02	0.04	0.20	0.40	0.64	0.86
VIII Mountain	0.04	0.10	0.45	0.87	1.44	1.98
IX South Pacific	0.67	1.16	4.86	8.01	12.71	17.55
X North Pacific	0.07	0.14	0.70	1.25	2.00	2.72
U.S.	1.24	2.56	12.63	24.24	39.22	52.36

* 1982 discounted present values in billions of 1980 dollars for a 7-year time horizon (1989-95) and a 10 percent discount rate. Individual entries may not sum to U.S. totals due to independent roundoffs.

baseline. For example, the PM10 (70, 250) standard would produce air quality improvements in approximately 90 to 100 counties; the TSP (-/150) standard would result in benefits for approximately 500 counties.

FINDINGS AND CONCLUSIONS

This study estimates the incremental benefits of alternative ambient air quality standards for PM. The principal conclusion of the study is that the benefits are economically significant but that the estimates of benefits are highly uncertain. That is, the study provides a considerable amount of new information but care must be exercised in the use of the results. These conclusions are developed further below.

Estimates of Incremental Benefits

Limitations in available data, methods and scientific evidence make it difficult to estimate the benefits of alternative PM NAAQS. Each limitation introduces uncertainty and requires an assumption or an exercise of judgment to fill the gap. The approach taken in this study is to evaluate the consequences of alternative assumptions and judgments. This provides the most complete information possible and reduces the possibility of biased results.

As an example, under the most extreme assumptions, the discounted present value of benefits of the PM10 (70, 250) Scenario B standard range from as low as $160 million to as high as $146 billion. The lower estimate arises when the most restrictive assumptions are used throughout the analysis; the higher estimate results from use of much less restrictive assumptions.*

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* The stated range does not reflect two additional sources of uncertainty: 1) the air quality data approximations required in the absence of detailed dispersion modeling; and 2) the possible existence and magnitude of benefits below the Staff Paper lower bounds. Incorporating the first of these could potentially reduce both ends of the range by a factor of 2 to 4. Imposing the Staff Paper lower bound of 110 $\mu g/m^3$ annual average TSP on the health studies makes the range $140 million to $99 billion.

Using a somewhat less extreme set of assumptions leads to a narrower range of estimates. For example, with the standard mentioned above, a more realistic estimate of the range is $1 billion to $50 billion. This is the range identified previously in Tables 1-10 and 1-11. The range in this case is due to the use of alternative aggregation procedures. As noted in the discussion of the tables and Table 1-9, the lower end of the range is still likely to be an underestimate because of incomplete coverage of benefits. The upper end is also possibly an overestimate due to some double counting of benefits. An alternative method for estimating benefits (property value and wage studies) is consistent with this assessment and suggests a still narrower range of about $3 billion to $40 billion. This range would be most consistent with aggregation procedures B through E. It is difficult to narrow the range further without making more controversial judgments.

Another finding of the study is that incremental benefits generally increase as standards become more stringent and as implementation dates are advanced. This is true for both A and B scenarios and for all aggregation procedures. (The few exceptions arise when lower bounds are applied.) For example, with the B scenarios, benefits increase by a factor of 3 to 4 when moving from the least restrictive standard to the most restrictive standard. The increase results from two changes: 1) the larger improvement in air quality in each geographic area, and 2) the addition of more areas that will experience an improvement. However, this does not necessarily imply that the most restrictive standard is the economically preferred standard because the offsetting costs of pollution control must also be taken into account. A comparison of benefits with costs is done in Section 2.

<u>Limitations of the Estimates</u>

The sources of uncertainty in the benefit analysis are identified in the basic report sections. They have also been summarized in this section. They include such problems as: conflicting evidence among available scientific studies; uncertainty about the concentration ranges over which health effects occur; incomplete coverage of benefit categories; alternative methods for valuing health improvements; alternative methods of aggregation; and approximations introduced by the methods for estimating air quality improvements. All of these problems have been addressed in the study. Where possible, the magnitude of the uncertainty has been estimated directly. These estimates of uncertainty are reflected in the range of benefit estimates discussed previously. Where quantitative estimates of the uncertainty are not possible, conservative assumptions are used instead, and the sources of uncertainty are described qualitatively.

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SECTION 2

NET BENEFIT ANALYSIS

SECTION 2

NET BENEFIT ANALYSIS

INTRODUCTION

This section of the report provides comparisons of the estimated benefits and costs of the several alternative National Ambient Air Quality Standards for particulate matter (PM NAAQS). These comparisons of benefits and costs are referred to as benefit-cost analyses. They provide a framework for evaluating the economic effects of alternative regulatory policies and are presented as a response to Executive Order 12291 which requires the identification of the regulatory alternative which will produce the maximum net benefits to society.

The implementation of a particular air quality standard, for example, may lead to favorable health and other welfare effects that represent a clear improvement in the economic well-being of some members of society. At the same time, however, costs may be incurred as additional resources are committed to reduce emissions to permissable levels defined by these air quality standards. These costs cause a reduction in the economic well-being of some members of society. Given that these costs are generally incurred as air quality is improved, an evaluation of the net impact of the standards on society's economic well-being requires an assessment of both the benefits and costs associated with each of the alternative PM NAAQS.

Some necessary background concepts are developed immediately below. In particular, the economic criteria employed to evaluate the alternative PM NAAQS are described. Proper methods of conducting benefit-cost analyses are reviewed next. Following this, the estimates of both benefits and costs are described; comments on the appropriateness of these estimates for use in the benefit-cost analysis are provided. Next, the limitations of benefit-cost analysis are discussed. The results of the benefit-cost analyses are then presented. Finally, summary remarks, conclusions, and qualifications are offered.

BENEFIT-COST ANALYSIS: EVALUATION CRITERIA

Air quality regulations affect society's economic well-being by causing a reallocation of productive resources within the economy. Specifically, resources are allocated towards the production of cleaner air and away from other goods and services that would otherwise be produced. Benefit-cost analysis provides a method for assessing the desirability of the alternative PM NAAQS in terms of their impacts on the allocation of economic resources. These air quality standards are evaluated in terms of two established criteria: cost-effectiveness and efficiency.

Incremental Benefits and Costs. An analysis of the incremental benefits and costs associated with each of the alternative PM NAAQS is required for an evaluation of both the cost-effectiveness and the relative efficiency of the alternative ambient air quality standards. These are defined as follows:

- The incremental benefits associated with a given PM NAAQS are defined as the additional benefits resulting from improvements in air quality over baseline air quality levels.
- The incremental costs associated with a given PM NAAQS are defined as the additional costs that are incurred to achieve and maintain improvements in air quality over the baseline levels.

Note that both incremental benefits and incremental costs are computed relative to baseline air quality levels.* The term "incremental net

* Recall that "baseline" air quality levels are intended to reflect those air quality levels that would prevail in the absence of the implementation of any of the alternative PM NAAQS (see Section 1 for a more detailed description).

benefits" refers to the difference between incremental benefits and incremental costs.

Cost-Effectiveness

An analysis of the cost-effectiveness of PM NAAQS is employed to reduce the set of alternatives that are evaluated in terms of economic efficiency. Inferior standards are those which require higher costs to achieve the same or smaller benefits than dominant alternatives. An inferior standard is not "cost-effective" since the same or higher incremental benefits can be achieved by adopting a less costly standard. Those alternative PM NAAQS identified as being inferior need not be further evaluated in terms of economic efficiency.

Efficiency Criterion

The efficiency criterion is used to evaluate the economic desirability of the reallocation of resources that occurs as the result of the adoption of an alternative PM NAAQS. A given air quality standard is efficient in the economic sense if, as a result of its implementation, at least one individual's well-being is improved without reducing the well-being of any other member of society. The allocation of resources associated with an efficient standard is economically preferred to the allocation that exists prior to its implementation.

It should be recognized, however, that those individuals enjoying the benefits of improved air quality are not generally the same as those who bear the cost of controlling pollution emissions. As a result, the economic well-being of some members of society may be reduced and the strict criterion stated above will be violated. This need not be the case, however, if those individuals benefiting from improved air quality are required to compensate those who bear the costs of pollution control. Under such a compensation scheme, a given pollution standard would be judged efficient if those individuals receiving benefits could potentially compensate exactly those individuals bearing the costs of the standard, and still realize a net gain in economic well-being. As is typically the case with applied benefit-cost analysis, this is the efficiency criterion that is adopted in this analysis.

The exact compensation arrangement described above will not be implemented. Tax credits on investments in pollution control equipment will redistribute some of the costs of emissions control, but these and other provisions will not completely resolve all equity issues. Consequently, the distribution of estimated benefits and costs among various sectors of the economy is described for the alternative PM NAAQS later in this section of the report.

In addition to determining whether a given air quality standard is efficient, it is also possible to rank the alternative PM NAAQS in terms of relative efficiency. The PM NAAQS that is most efficient, relative to the alternatives considered, is the one which provides the largest incremental net benefits. An analysis of the relative efficiency of the alternative PM NAAQS considered is described later in this section.

Scope of Analysis

Efficiency is only a necessary but not a sufficient condition for establishing the economic desirability of an air quality standard. Since there are generally both benefits and costs associated with achieving and maintaining baseline air quality levels, it is possible that the total costs could exceed the total benefits associated with a PM NAAQS, even if incremental net benefits are positive.* This could occur if the cost of baseline controls exceeds the benefits associated with baseline air quality levels. If this were the case, society might be better off if no air quality standards are adopted, including those already in place to achieve baseline levels of air quality.

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* Total benefits include the benefits associated with baseline controls as well as the incremental benefits realized as a result of the adoption of a PM NAAQS. Similarly, total costs include both baseline control costs and incremental costs.

A standard for which total benefits exceed total costs is termed "feasible". As this definition indicates, estimates of both baseline and incremental benefits and costs are required to assess the feasibility of the alternative PM NAAQS. Estimates of the benefits associated with baseline controls, however, are unavailable. The alternative PM NAAQS were evaluated by a sufficient test for feasibility which compared total costs with incremental benefits under the assumption that no benefits are associated with baseline controls. These tests, however, often produced inconclusive results in that the feasibility of many alternative standards could not be determined. Consequently, the results of these tests are not reported.*

Ideally, all feasible and cost-effective PM NAAQS should be evaluated in order to identify the one which maximizes society's well-being as a result of improvements in ambient air quality. Within the context of applied benefit-cost analysis, however, it is usually possible to consider only a limited set of discrete alternatives. Such is the case with this analysis. Consequently, the focus is on the relative efficiency of a limited selection of alternatives and not the identification of the most efficient of all possible feasible and cost-effective PM NAAQS.

BENEFIT-COST ANALYSIS: METHODOLOGY

Appropriate methods of testing for both the cost-effectiveness and efficiency conditions are described immediately below. As was stated previously, the tests for cost-effectiveness and efficiency require analyses of the incremental benefits and costs associated with each of the alternative PM NAAQS. These benefit-cost analyses are limited in that they are not employed to evaluate the distributional impacts of these air quality standards; consequently, a brief discussion of this issue is also provided.

* Estimates of baseline control costs, which are necessary to replicate the sufficient tests for feasibility, are reported later in this section.

Benefit-Cost Analysis: Incremental Benefits and Costs

An analysis of the incremental benefits and costs associated with the alternative PM NAAQS can be conducted in the following manner:

- Compute the estimated incremental benefits associated with each alternative PM NAAQS.
- Similarly, compute the estimated incremental costs associated with each alternative standard.
- Compute the estimated net incremental benefits (i.e., incremental benefits minus incremental costs) generated by each alternative standard.
- Compare the estimated net incremental benefits for each of the several alternative standards.

Any alternative PM NAAQS that is associated with higher incremental costs, but the same or smaller incremental benefits than some other standard, is inferior or cost-ineffective and need not be further evaluated in terms of efficiency. Any alternative PM NAAQS that produces positive net incremental benefits will provide a more efficient allocation of resources than what would occur under the baseline air quality scenario. The PM NAAQS that produces the largest positive net benefits will produce the most efficient allocation of resources among the standards considered. When the net incremental benefits associated with a standard are negative, the baseline air quality scenario yields a more efficient allocation of resources.

Distributional Effects

There are two reasons why the distributional impacts associated with the alternative PM NAAQS are an important issue. These reasons are:

- The benefits and costs associated with the alternative standards are not likely to be distributed evenly across various sectors of the economy, thus raising equity issues.

- The distribution of adverse impacts may affect the measurements of costs that are appropriate for use in the benefit-cost analyses.

Both of these points are discussed below in greater detail.

It has already been noted that those individuals who enjoy the benefits of improved air quality are not generally the same as those who bear the cost of controlling emissions. Absent any arrangement whereby beneficiaries compensate those incurring costs, it is likely that the implementation of an air quality standard will increase the economic well-being of some individuals and reduce the well-being of others, thus raising an equity issue. The distribution of costs among those incurring the expenses of emissions controls raises an additional potential equity issue.

These distributional or equity effects are not typically evaluated within the framework of applied benefit-cost analysis. In order to do so, it would be necessary to obtain estimates of the values that society places on the distributions of economic well-being associated with each of the alternative PM NAAQS. Estimates of these values are unavailable. As a result, a separate analysis of these distributional impacts is provided. The results of this analysis are summarized later in this section. It should be stressed, however, that no judgments regarding the desirability of these distributional effects are offered; instead, these impacts are only described.

The potential distribution of adverse economic impacts associated with the alternative PM NAAQS should also be considered in measuring appropriate costs for use in the benefit-cost analysis. The cost estimates provided by the emissions control phase of the study, for example, are based on the assumption that no plants close or reduce production under the burden of additional emissions control costs. Plant closures are likely to produce an upward bias in these cost estimates. If a significant number of plants would, in fact, cease operation when faced with additional control costs, downward adjustments to these earlier cost estimates may be necessary before they can be used appropriately in the benefit-cost analyses.* This issue is discussed in more detail later in this section.

MEASUREMENT OF BENEFITS AND COSTS

A clear understanding of several conceptual issues is necessary for a proper interpretation of the estimated benefits and costs that are compared in the benefit-cost analysis. These conceptual issues are discussed immediately below. Following this, the estimates of both the incremental benefits and incremental costs associated with each of the alternative PM NAAQS are discussed. The scope of benefits and costs included in these estimates are also described and the estimation techniques employed are reviewed briefly. Finally, a discussion of the consistency between these benefit and cost estimates is provided.

Measurement of Benefits and Costs: Conceptual Issues

The beneficial effects of improved ambient air quality can be measured as the value that individuals place on the opportunity to consume cleaner air. The conceptually correct valuation of this opportunity requires the identification of individuals' willingness to pay for cleaner air (or to be compensated for deterioration of air quality).** Where possible, willingness to pay is the measure of benefits that is adopted in this analysis. Estimates of society's willingness to pay for cleaner air do not exist for all benefit categories, however. Alternative measures are used for those benefit categories included in the analyses for which estimates of willingness to pay are unavailable.

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* Descriptions of several potentially adverse impacts associated with the alternative PM NAAQS are described in a separate report by another contractor (1).

** The appropriateness of willingness to pay versus willingness to be compensated depends on the property right endowments of receptors. Because of income constraint considerations, willingness to be compensated may be greater than willingness to pay.

Similarly, an appropriate measure of the cost of pollution emissions control can be measured as the value that society places on those goods and services not produced as a result of resources being diverted to the production of improved air quality. Again, the conceptually correct valuation of these costs requires the identification of society's willingness to pay for these foregone consumption opportunities that would otherwise be available.

As the preceding discussion suggests, only impacts that result from a reallocation of economic resources are included in the benefit and cost estimates. The implementation of a PM NAAQS, however, may be accompanied by price adjustments and subsequent short-run income transfer effects. For example, a sudden demand for emissions control devices resulting from a more stringent air quality standard may initially result in higher prices for these devices. Increased income in the form of excess profits will then accrue to the manufacturers of these devices; however, this favorable effect occurs at the expense of those who must pay the higher prices. The total effect is merely pecuniary.* These pecuniary effects are not and should not be included in the benefit estimates that follow.

It is also possible that air quality standards may generate indirect economic impacts. One example of an indirect effect is the transfer of income to owners of recreational facilities as individuals whose health is improved as a direct result of better air quality increase their use of the recreational facilities. Indirect costs and benefits which represent real (as opposed to pecuniary) effects should be included in benefit and cost estimates. As a practical matter, however, it is often very difficult to measure all indirect effects and to determine whether they are real or pecuniary in nature. Consequently, the benefits and costs considered in this analysis include only the direct effects of the alternative PM NAAQS. The exclusion of possible indirect effects may mean that these estimated

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* "Income transfers" refer to redistributions of income that do not result directly from production of goods or services. These transfers are referred to as "pecuniary".

benefits and costs understate the total effects of the alternative air quality standards.

Estimates of Benefits

The benefit-cost analyses described later in this section represent relatively straightforward comparisons of the estimated benefits and costs associated with alternative PM NAAQS. Because of this, the uncertainty that surrounds both estimated benefits and costs may be obscurred. Nonetheless, the validity of the benefit-cost analyses depends critically on the accuracy of estimated benefits and costs. Any uncertainty embedded in these estimates will carry over to the benefit-cost analyses.

The sources of uncertainty in the benefits estimates have already been described in detail earlier in Section 1. These sources of uncertainty fall into the following three general categories:

- Scope and magnitude of air quality improvements.
- Valuation of health and welfare improvements.
- Evidence of health and welfare effects.
- Coverage of effects/benefit categories.

Some of the degree of uncertainty can be estimated quantitatively. Ranges of estimated benefits have already been reported in Section 1. Benefit-cost analyses, however, are conducted only for the point estimates of benefits. Nonetheless, the results of these analyses should be interpreted in view of the uncertainty that does exist in the benefit estimates. Each of the major sources of uncertainty listed above is reviewed briefly below for the convenience of the reader.

Scope and Magnitude of Air Quality Improvements —

Benefits are estimated based on projected improvements in air quality associated with the alternative PM NAAQS. The projections of air quality improvements are also subject to uncertainty. This, in turn, creates an additional source of uncertainty to the benefit estimates.

The uncertainty surrounding the estimates of air quality improvements has already been described earlier in Section 1. The major sources of uncertainty include the following:

- Use of county-wide rollback to predict air quality changes at the worst-case monitor.
- Use of proportionality to predict air quality changes elsewhere.
- The failure to account for potential air quality improvements resulting from emissions controls in adjacent counties.
- Approximations required in converting among different PM measures (TSP, PM10, BS).
- Use of 1977-78 as a base year for predicting air quality.

The implications of these uncertainties associated with estimates of air quality improvements have already been discussed in detail in Section 1. The results of plausibility checks on some of the assumptions embedded in the air quality estimates have also been reported there.

Valuation of Health and Welfare Improvements —

Two general categories of benefits attributable to improvements in ambient air quality are included in the benefit-cost analyses.* These benefit categories are:

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* Studies based on property value models and wage models were also included in the benefit analysis as plausibility checks. However, since it is not possible to disentangle the health and soiling benefits from other benefits estimated by these models, they are not included in the estimates reported in this section in order to avoid possible double-counting. The property value and wage models are described in Sections 5 and 6 of this report.

- Health effects
- Soiling and material damage.

Estimates of benefits derived from these two categories were developed from previously conducted studies which examine the health and welfare effects of ambient particulate matter. These studies were selected after a thorough review of the literature and a careful evaluation of their suitability for use in estimating the benefits of the alternative PM NAAQS.

Health effects are further classified in terms of the risk of mortality, acute morbidity, and chronic morbidity. Measures of increased risk of mortality and morbidity as a result of physical effects caused by deteriorations in air quality are developed. The value placed on reductions in mortality rates attributable to alternative PM NAAQS reflects individuals' willingness to pay to reduce the risk of death and thus constitutes a theoretically correct measure of benefits. Nonetheless, there are large variations in the estimates of the value assigned to mortality risk reductions.

Benefits associated with reduced morbidity are based on: reductions in medical expenditures, the value of improved labor productivity due to reduced work days lost, and the value placed on increased opportunities to engage in non-labor activities.* These benefit estimates are likely to underestimate willingness to pay for improved air quality, since they do not include the value that individuals place on reductions in residual pain and suffering.**

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* In addition to lost time in the workplace, individuals may be forced to curtail non-labor activities as a result of morbidity caused by pollution emissions. The lost opportunity to engage in these activities are estimated at one-half of the wage-rate of affected individuals.

** Some medical expenditures are made to reduce pain and suffering induced by pollution emissions. However, prior to receipt of medical care services, and in some cases during and after provision of such services, pain and suffering occur. The reduction in this "residual pain and suffering" is not included in the benefit estimate.

Benefits attributable to reduced soiling and materials damage in both the household and industrial sectors rely primarily on economic models which identify associations between air quality and goods exchanged in private markets. By observing how consumption expenditure patterns of typical households vary in response to different levels of pollution emissions, it is possible to estimate the value these households place on various improvements in ambient air quality. In the industrial sector, benefits are estimated for two 2-digit SICs by employing econometric techniques which relate soiling or contamination to production costs. In general, these benefits reflect willingness to pay for improved air quality.

Evidence of Health and Welfare Effects —

Additional uncertainty is introduced to the benefit estimates because of uncertain evidence of the magnitudes of health and welfare effects associated with cleaner air. These sources of uncertainty include:

- Conflicting evidence across studies.
- Incomplete control for confounding factors.
- Use of study results from one time and area to estimate effects in another time and area.
- No information on the size distribution of particles present during the studies.
- Alternative functional forms possible.
- Sampling variation in coefficient estimates.
- Degree of risk at lower-level PM concentrations.

The degree of uncertainty introduced by some of the above sources can be estimated quantitatively. In these cases, the degree of uncertainty is reflected in the ranges of the incremental benefit estimates reported in Section 1.

Coverage of Effects/Benefit Categories —

The benefit estimates used in this analysis do not include a number of areas where benefits may arise. Limitations in the definition of certain data transformations, control strategy designs, and methodological issues precluded the inclusion of potential benefits attributable to improved visibility, possible climatic effects, and reductions in acidic depositions. In addition to these omitted benefit categories, potential benefits accruing to some sectors of the economy are also excluded from estimates used in the benefit-cost analysis. These omissions include potential benefits due to reduced soiling and materials damages to commercial, governmental, and institutional structures as well as some industrial structures. Furthermore, the estimates that are included focus exclusively on user value benefits and exclude potential non-user benefit categories such as existence, bequest, and option values.* The omission of these plausible benefit categories may cause the estimates used in this analysis to understate the true level of benefits associated with a particular PM NAAQS.**

Estimates of Costs

The costs of achieving and maintaining air quality levels associated with the alternative PM NAAQS were estimated by another contractor (2). As is the case with the benefit estimates, emissions control costs are not estimated with certainty. Consequently, a proper interpretation of the benefit-cost analyses requires an understanding of how emissions control

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* See Sections 1 and 8 for further discussion of non-user benefit categories.

** Benefits may also be understated even in those categories where benefits are measured if economic decision-makers have made prior behavioral adjustments in response to air quality changes. For example, observed pollution-induced morbidity may be reduced if individuals curtail outdoor activities because of perceived health risks associated with poor air quality. There is, however, a cost associated with this behavioral adjustment -- namely, the cost of the opportunity to engage in the foregone outdoor activities.

costs are estimated so that uncertainties and potential biases introduced by methodological compromises and data quality can be assessed.

Control Cost Estimation Procedure —

A fully detailed description of the procedures employed to estimate emissions control costs is beyond the scope of this report. The abbreviated description offered below is intended to serve as a basis for a later discussion of uncertainty and potential biases surrounding the cost estimates.

The approach employed to estimate emissions control costs can be viewed as a six-step procedure as illustrated in Figure 2-1. First, estimates of both emissions (TSP and PM10) and air quality levels nominally representative of 1978 conditions were developed, by county areas (and subcounty areas in selected cases). Estimates of TSP emissions were based on data from EPA's National Emissions Data Systems (NEDS); PM10 emissions were estimated from the TSP data by using a conversion process. TSP air quality data were obtained from EPA's Storage and Retrieval of Aerometric Data System (SAROAD). Since no PM10 data were available, PM10 air quality levels were derived from TSP data by using a 0.55 conversion factor.

In Step 2, a linear rollback approach was employed to project future air quality levels. Future emissions rates were projected by accounting for both the growth of new sources and the replacement of existing sources. Future air quality levels were then projected based on the presumption that all sources within an area contribute to air quality levels directly proportional to their emissions rates. Based on these estimates of future air quality levels, areas (counties or subcounty areas) projected to be in nonattainment with the alternative PM NAAQS were identified.

An inventory of control options and associated emissions was then developed for sources within areas projected to be in nonattainment with the alternative air quality standards. Only a single control strategy could be identified for many sources, however, and no control strategies

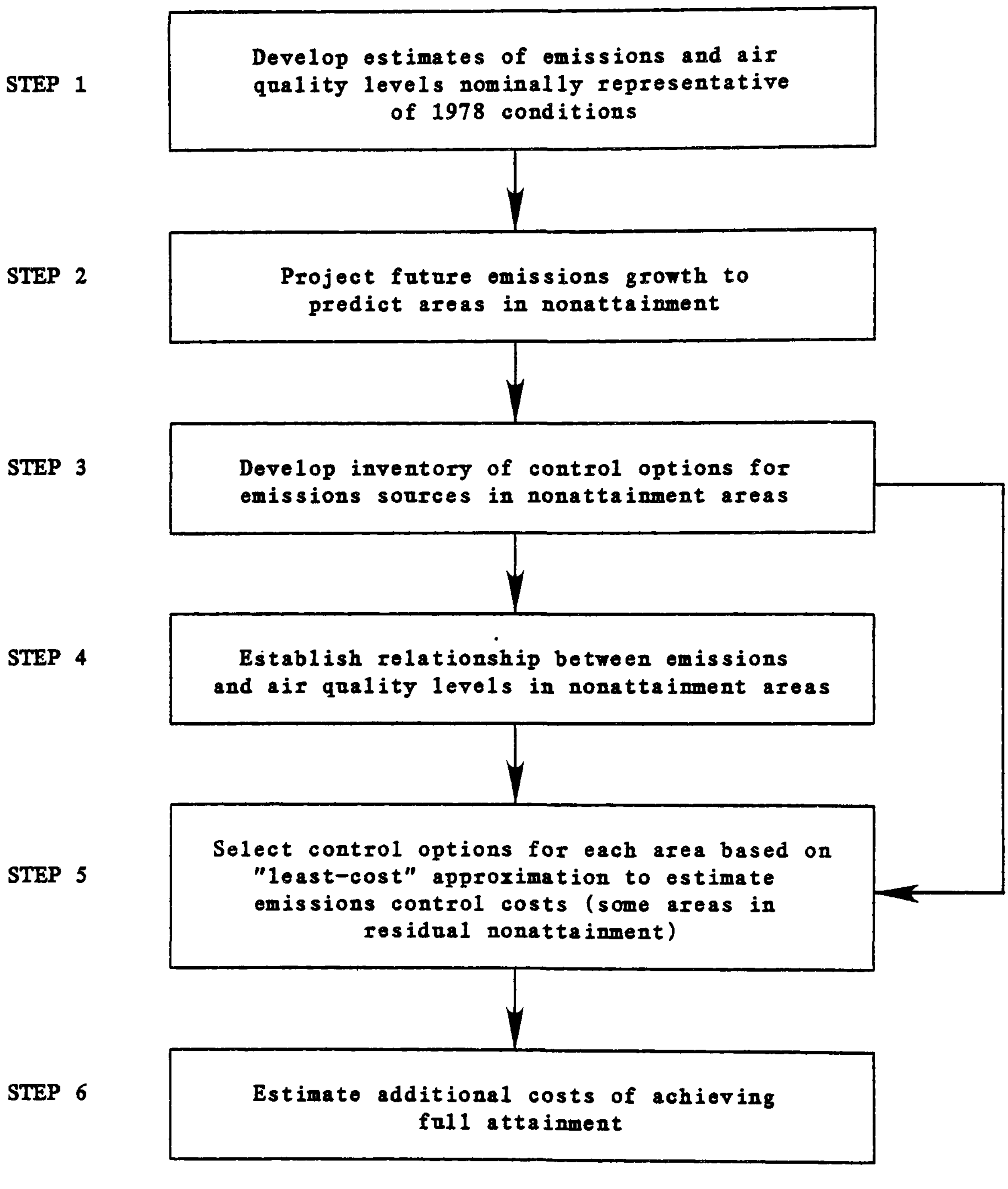

Figure 2-1. Basic Steps in Estimating Emissions Control Costs

could be identified for some other sources. In addition, control options were eliminated if the cost of emissions reductions was extraordinarily high based on current experience or if they cost more but reduced emissions less than another option. As a result of these combined factors, more than 50 percent of all sources were not considered as candidates for control in some scenarios analyzed.

Relationships between source emissions rates and area air quality levels were established next in Step 4. A modified linear rollback technique was employed. That is, it was assumed that all sources within an area contribute to air quality directly proportional to their emissions rates and inversely proportional to their effective stack height.

The cost of emissions control was then estimated (Step 5) by selecting control strategies that minimized costs (in terms of dollars per microgram of air quality improvement) for each area in nonattainment. Additional control options were applied incrementally until attainment with a given air quality standard was achieved or available control options were exhausted. This resulted in some areas being in "residual" nonattainment.

It should be noted that when the "least-cost" control strategies were selected in Step 5, it was assumed that controls put in place at the beginning of the implementation period were sufficient to reduce emissions to required levels for the entire implementation period. This typically results in greater than necessary controls of emissions during the early phases of the implementation period since baseline ambient PM concentrations typically increase over time because of growth in the number of emissions sources.

In Step 6, the cost of eliminating residual nonattainment was estimated based on the cost of achieving partial attainment (Step 5) and the degree of residual nonattainment. In particular, the additional cost was estimated by multiplying the national cost of partial attainment by the national average ratio of the additional air quality improvement needed in each residual nonattainment county to the air quality improvement already achieved in each such county. This additional cost was then added to the cost of partial attainment in order to estimate the full cost of bringing all areas into full attainment.

As was noted earlier, uncertainty and potential biases are introduced to the control cost estimates from both methodological compromises and data quality. In addition, there is a third issue -- the difference between emissions control costs and economic costs -- that should be addressed in assessing the appropriateness of the cost estimates for use in the benefit-cost analyses. These issues are discussed briefly below. Where possible, the directions of potential biases are examined.

Methodological Compromises —

Because of the scope of the nationwide emissions control cost study, and time phasing and resource considerations, it was necessary to make several methodological compromises. Those compromises that introduce uncertainty and potential biases to the cost estimates include:

- Use of design monitors.
- Use of the modified linear rollback procedure.
- Consideration of a limited set of control options.
- The use of a national average measure of residual non-attainment in estimating the cost of eliminating residual nonattainment.
- Placing some areas under controls greater than necessary to achieve attainment.

Each of these potential problems is discussed immediately below.

Design Monitors -- In order to simplify the analysis, the design value was obtained as the reading of the monitor showing the highest PM concentration level in an area.* This may be a poor measure of actual air quality on an area-wide basis since the highest monitor naturally reflects PM concentration levels that are higher than at other points within the area. Other things being the same, the use of the highest reading as the design value will tend to cause an upward bias in the cost estimates since the overall level of required control within an area will be overstated. The magnitude of this bias, however, is not predictable in a straightforward fashion, given the use of the modified linear rollback procedure. This problem is discussed immediately below.

Modified Rollback — The modified linear rollback assumption was employed as an alternative to detailed dispersion modeling. As was explained earlier, this procedure assumes that all sources in an area contribute to the PM concentration levels recorded at the design monitor directly proportional to their emissions rates and inversely proportional to effective stack heights. Unfortunately, the direction of the bias introduced to the control cost estimates because of this factor cannot be predicted *a priori*.

All emissions sources within an area may not contribute to concentration levels at the design monitor. Consequently, it may not be necessary to control all sources; as a result, estimated control costs may be overstated. It may be the case, however, that sources proximate to the design monitor with high control costs contribute heavily to the reading. Estimated control costs could be understated if these sources were not controlled (or not controlled enough) under the optimal control strategy.

It is also noted that the rollback procedure employed to project future ambient air quality and the approach used to estimate emissions control costs are inconsistent. In establishing the relationship between

* It should be noted that this is not necessarily indicative of the highest concentration in an area. Limitations on the number of monitors and their placement (e.g., highly elevated to avoid vandalism) can mean that the design value is not indicative of the highest concentration. However, such values are presumed to be good indicators of higher concentrations.

emissions control strategies and improvements in air quality, it was assumed that sources contribute to air quality inversely proportional to their effective stack heights. Stack heights were not considered, however, in projecting future air quality levels from the base year. The direction of the bias to estimated control costs because of this inconsistency is not known.

Limited Set of Control Options -- Two or three emissions control options could be identified for some sources (e.g., boilers). For many emissions sources, however, only one or no emissions control options could be identified. If, indeed, other control options less costly than those selected by the "least-cost" algorithm actually exist, estimated control costs will be overstated.

Residual Nonattainment — After all "cost-effective" control strategies were adopted, some counties were still found to be in residual nonattainment with the alternative PM NAAQS. In these cases, the additional cost of achieving full attainment was estimated based on the cost of achieving partial attainment and the degree of residual nonattainment. The estimate was developed by multiplying the national cost of achieving partial attainment by the national average ratio of the additional air quality improvements needed in each residual nonattainment county to the air quality improvement already achieved in each such county. This additional cost was then added to the cost of partial attainment in order to estimate the full national cost of bringing all areas into full attainment. Since this additional cost is a national estimate, no regional breakdowns of control costs were available for the type B scenarios (complete attainment scenarios).

An alternative procedure for estimating the additional cost would have been to assume that the additional air quality improvement needed in each county would have a cost per microgram equal to the average or marginal cost* per microgram for the air quality improvement already achieved in that county. This approach would have provided a more accurate estimate and allowed a regional breakdown of costs. It was not undertaken due to time constraints. The relationship between the two approaches will depend on whether counties with high partial attainment costs are in about the same degree of residual nonattainment as counties with low partial attainment costs. If high cost counties generally experience more residual nonattainment, then the procedure actually used may lead to a lower estimate compared to using average cost. If high cost counties generally experience less residual nonattainment, then the procedure used may lead to an estimate above what would have been predicted by using average cost. The estimates of the additional cost of achieving full attainment are thus highly uncertain.

Control Strategies Below the Standard — Emissions were projected to 1995 and the resulting air quality level was estimated accordingly.** Then, controls necessary to achieve required air quality levels for the entire implementation period (to 1995) were put in place in the initial implementation year (1987 or 1989). In many cases, this resulted in more control than necessary to achieve air quality levels sufficient to meet the alternative standards. This approach is likely to produce an upward bias in the cost estimates used in the benefit-cost analyses. In fact, the source of the bias is twofold: 1) capital equipment might be installed earlier than necessary (and depreciated more quickly than need be) resulting in an increase in the present value of estimated costs; 2) some unnecessary operating and maintenance costs might be incurred in those

* Strictly speaking, marginal cost is the conceptually correct measure to use in estimating the cost of eliminating residual nonattainment. Since marginal cost usually exceeds average cost, use of the latter measure would have biased estimated costs downward. It is noted, however, that use of average cost might be justified based on reasoned judgment: first, one reason that cost-effective control options were exhausted is that many sources were not considered as candidates for control; second, it is possible that new technologies may produce less costly control options in the future.

** See Section 9 for a more detailed discussion.

years during which the controls resulted in air quality levels lower than those required by the alternative PM NAAQS.

Data Availability and Quality —

A number of problems involving both the availability and quality of data surfaced during attempts to estimate the emissions control costs associated with alternative PM NAAQS. These data problems include the following:

- The NEDS emissions data base may not reflect actual 1978 conditions.
- The point source data employed is both incomplete and occasionally inaccurate.
- Secondarily formed aerosols are not accounted for in the emissions control analysis.
- Air quality data is incomplete.

Each of these data problems is discussed briefly below.

<u>The 1978 NEDS Data Base May Not Represent Actual Conditions</u> — The NEDS 1978 data base is not completely updated annually. Because of this, the data may reflect both emissions rates and control strategies that were in place in some earlier year. This particular data problem might produce either a downward or an upward bias in the cost estimates used in the benefit-cost analyses. Estimated control costs could be biased downward if the least-cost control algorithm selected low-cost sources for control that actually had substantial controls already in place instead of higher-cost sources which should have been controlled. Alternatively, control costs could be overestimated if the 1978 NEDS data base overstates emissions rates and the overall degree of control necessary to satisfy the requirements of the alternative PM NAAQS.*

* This latter problem would also cause estimated benefits to be overstated since necessary air quality improvements would likewise be overstated.

Incomplete and Inaccurate Point Source Data — Of a total of 5.72 million tons per year (TPY) of TSP emissions included in the analysis for purposes of projecting future air quality, only 3.55 million TPY could be accounted for in the point source emissions data base. This discrepancy was caused by both incomplete and/or inaccurate point source data. It is important to note that this particular data problem is likely to cause pollution abatement costs to be overestimated, and the magnitude of the bias is potentially large. This overestimate of emissions control costs is caused by the fact that roughly 40 percent of all source candidates for emissions control were omitted from the feasible solution to the least-cost algorithm. If any of these omitted point sources exhibit marginal control costs less than those actually selected for control, estimated control costs are biased upward.

Secondarily-Formed Aerosols Are Not Accounted for in the Analysis — The emissions control cost analysis does not account for secondarily-formed aerosols which can account for a large percent of total ambient PM10 in some areas. The effect of not including these secondarily-formed emissions is to overstate the degree of control possible for ambient PM10 through traditional strategies, thus causing an underestimation of pollution control costs.

Air Quality Data — As was noted previously, PM10 air quality data are not currently available. The PM10 air quality data used in the control cost analysis was obtained by applying a 0.55 conversion factor to TSP air quality measures in the base year. This conversion factor was estimated through an analysis of data available from EPA's inhalable particulate (PM15) network. It should be stressed, however, that the conversion factor is likely to vary across geographic areas. Although the direction of potential bias due to the use of the conversion factor cannot be predicted, its use does introduce uncertainty to the cost estimates.

In addition, valid air quality data for many counties were unavailable. If valid design values were unavailable for counties designated as being in attainment or unclassifiable, they were eliminated from the cost analysis. If counties were classified as being in nonattainment, default design values were set at one $\mu g/m^3$ above the standard violated. In other cases, valid air quality data for one of the averaging periods were unavailable and default design values were estimated through regression analysis which related one averaging period to another. Again, these data deficiencies introduced additional uncertainty to the cost estimates.

In some areas, valid air quality data were unavailable for 1978, but observations were available for earlier years (e.g., 1975-1977). The earlier observations were substituted as 1978 values in these cases. It is noted that this approach potentially causes a mismatch between emissions sources and air quality. The direction of potential bias that this factor introduces to the cost estimates, however, cannot be predicted a priori.

Emissions Control Costs and Economic Costs —

The estimated emissions control costs should be viewed as approximations of the conceptually correct measure of costs. Recall that the conceptually correct measure of costs is reflected by society's willingness to pay for the goods and services not produced as a result of economic resources being diverted to the production of improved air quality. The estimated pollution control costs, however, are based on engineering estimates of the costs of equipment and labor required to control emissions to permissible levels.

These estimates will correspond exactly to the conceptually correct measure of costs only if two conditions are satisfied. First, affected polluters must be able to pass forward all emissions control costs to consumers through price mark-ups without reducing the market quantity demanded of goods or services they sell. Otherwise, the estimated direct pollution control costs will overstate the true economic costs associated with the alternative PM NAAQS. Second, the prices of pollution control resources (e.g., pollution control equipment and labor) used to estimate costs must correspond to the prices that would prevail if these factors were sold in perfectly competitive markets. For example, if excess profits are earned on pollution control equipment, the estimated emissions control costs will overstate the conceptually correct measure of costs.

The estimated pollution control costs reported in this section do not account for possible long-run adjustments to the PM NAAQS. Based on the findings of the Economic Impact Analysis (3), for example, it is anticipated that some plants will close under the burden of additional emissions control costs. Moreover, it is expected that some of the remaining plants will expand production to compensate at least partially for output lost due to the closures. The failure to account for these adjustments is likely to produce a net upward bias in the cost estimates.*

In addition, the cost estimates reported here do not include possible transition costs that some industries may experience as adjustments to the alternative PM NAAQS occur. For example, some temporary unemployment may occur as some affected plants reduce production or close. This effect, however, is expected to be mitigated at least partially by increased employment in other plants. The results of the Economic Impact Analysis, however, suggest that the net impact of these transition costs are not likely to affect significantly the cost estimates used here in the benefit-cost analyses.

Administrative, Monitoring, and Enforcement Costs —

The administrative, monitoring, and enforcement (AME) activities that accompany an air quality standard are not fully reflected in the emissions control cost estimates provided by the cost contractor. These AME costs

* Estimated costs should be reduced because of the closures since these plants will not implement pollution control strategies. At the same time, costs for the remaining plants should be adjusted upward as they expand production. The net effect, however, is likely to reduce costs, since the additional cost of expanding production for the remaining plants presumably will be less than the extra costs that would be incurred by plants which close. Otherwise, these latter plants would remain competitive instead of closing down operations. See Reference (1) for further discussion of this and other related issues.

may be borne both by directly affected firms and institutions and different levels of government. It is the latter AME costs that are not reflected in the emissions control cost estimates.* The proper measure of these AME costs should reflect the incremental costs of implementing and maintaining a given alternative PM NAAQS.

Estimates of the long-run annualized AME costs for state and local agencies, as well as for EPA Regional offices, indicate that the government sector resource requirements should not exceed $50 million annually (1981 dollars).** Relative to the magnitudes reported for the benefits and costs of control, these additional expected AME expenditures are small. As a consequence, these costs are not likely to affect appreciably the outcome of the benefit-cost analyses. Nevertheless, if a complete measure of costs is to be developed, an adjustment to the cost of control estimates is required. Based on the annualized AME costs reported above and on an examination of historical data, an adjustment factor of 4 percent of the discounted present value of engineering and operation costs appears reasonable. Thus, final estimates of control costs used in the benefit-cost analyses are increased by 4 percent over the discounted present values of the estimated costs obtained from the cost contractor.

Control Cost Truncation —

The costs provided by the cost contractor are based on a 15-year engineering life for the emissions control equipment beginning at the 1987 (TSP) or 1989 (PM10) implementation dates. In this section, these costs are adjusted to reflect a shorter time horizon (i.e., to 1995) by aggregating the annualized stream of costs from the implementation date only through 1995 and then applying the appropriate discounting formula. The

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* Some institutions affected by the alternative PM NAAQS are government agencies (e.g., utilities owned by local governments and government-maintained roads). Those AME costs that will be incurred internally by these directly affected government institutions have already been included in the cost estimates provided by the cost contractor.

** See Reference (3).

benefit-cost analysis is truncated at 1995 because of the uncertainty in projections of emissions levels beyond this date.

Costs Associated With Alternative PM NAAQS —

Estimated costs for each alternative PM NAAQS for both the A and B scenarios are summarized in Table 2-1.* As is the case with the benefit estimates, these costs are "incremental" in the sense that they are calculated relative to the baseline controls. Although direct pollution control

Table 2-1

SUMMARY OF INCREMENTAL COST ESTIMATES

Standard	Point Estimate of Incremental Costs*	
	A Scenario	B Scenario
PM10 70 AAM/250 24-hr., 7 yr.	0.50	0.95
PM10 55 AAM 7 yr.	0.90	2.52
PM10 55 AAM/250 24-hr., 7 yr.	0.93	2.57
PM10 55 AAM/200 24-hr., 7 yr.	0.95	2.54
PM10 55 AAM/150 24-hr., 7 yr.	1.26	3.53
PM10 48 AAM/183 24-hr., 7 yr.	1.32	3.36
TSP 75 AGM/260 24-hr., 7 yr.	1.08	2.61
TSP 150 24-hr., 7 yr.	1.78	5.96
TSP 75 AGM/260 24-hr., 9 yr.	1.61	4.02
TSP 150 24-hr., 9 yr.	2.63	8.95

* Expressed as the 1982 discounted present value in billions of 1980 dollars. Figures include estimated AME costs.

Source: Reference (2).

* Recall that some areas remain in residual nonattainment under the A scenario while all areas are in full attainment with the alternative standards under the B scenario.

costs do exhibit some sensitivity to various assumptions and conditions which underlie their derivation, no attempt is made to develop a range of incremental cost estimates which reflect this uncertainty.*

It is noted that the incremental costs associated with the most stringent of the PM10 standards are greater than those associated with the TSP 75 AGM/260 standard, even though the latter is listed as being more stringent. Two explanations of this phenomenon are:

- The counties projected to be in nonattainment with the PM10 standards sometimes differ from those expected to violate the TSP standard.
- PM10 and TSP control options differ because of different emissions sources and different particle sizes.

The figures displayed in Table 2-1 represent estimates of the incremental or additional costs of achieving and maintaining the air quality levels associated with the alternative PM NAAQS. These estimates do not include the costs of achieving and maintaining baseline air quality levels. Estimates of baseline control costs for the 1987-1995 implementation period range from $31.4 billion to $40.4 billion annually, expressed as the present discounted value of 1980 dollars in 1982. Comparable cost estimates over the 1989-1995 implementation period range from $21.8 billion to $28.0 billion.** The total costs associated with the alternative PM NAAQS are estimated as the sum of appropriate estimated baseline costs and the estimated incremental costs reported in Table 2.1.+

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* The results of several sensitivity analyses are documented in Reference (2).

** See Reference (4).

+ Sufficient tests for the feasibility have been briefly described earlier in this section. These tests can be replicated by subtracting the estimated total costs associated with each alternative standard from the corresponding estimated incremental benefits reported in Tables 1-11 through 1-14 in Section 1. The midpoints of the ranges were used as estimates of baseline control costs (i.e., $35.9 billion and $24.9 billion, respectively, for the 7- and 9-year implementation periods).

Consistency of Benefits and Costs Estimates

Although the incremental benefit and cost estimates used in this benefit-cost analysis are estimated using different methodologies, they are consistent and comparable in the following respects:

- Each is based on the same air quality information.
- Each reflects the same time horizons.*
- Each uses similar assumptions to project industry and population growth from the implementation date through 1995.
- Each uses a discount rate of 10 percent to obtain a present discounted value and an estimate of annualized benefits and costs.
- Each are valued as 1980 dollars in 1982.

The air quality data used in the benefit analysis were generated as part of the procedure employed to estimate the costs associated with each standard. Thus, estimates of both benefits and costs are based on identical assumptions regarding air quality levels.

Both benefits and costs accrue over time. When appropriate, similar growth factors are projected to both benefits and costs in order to ensure consistency between the two time streams.** For convenience, they are expressed in terms of their present discounted values in 1980 dollars in 1982.

For each alternative PM standard under consideration, benefits and costs are measured from the implementation date through 1995. It was

* As noted earlier, an adjustment factor is applied to the incremental cost estimates in order to make them consistent with the time-horizon used in the benefit analysis.

** Both analyses used projections of future industry and population growth. Although the projections were obtained from different sources, they were very similar in magnitude. For a comparative analysis, see Reference (5).

judged impractical to extend the benefit-cost analysis past this date, given the modeling uncertainties which arise when growth factors are incorporated into the analyses. Fortunately, the process of discounting causes both benefits and costs which may accrue in the distant future to be small relative to the present. Thus, the truncation of benefit and cost estimates in 1995 may not greatly affect the outcome of the benefit-cost analyses.

A constant real discount rate of 10 percent is used to discount the time streams of benefits and costs back to 1982. This real discount rate is prescribed by the Office of Management and Budget. Much debate surrounds the proper choice of the discount rate, and there is no clear concensus on this issue.* It is likely, however, that a real discount rate of 10 percent is too high.

It is also important to recognize, however, that benefits and costs compared in the benefit-cost analyses are inconsistent in some respects. These inconsistencies include the following:

- The costs of controlling emissions in nonattainment areas are likely to improve air quality in adjacent areas; however, these air quality improvements are not estimated, and thus the resulting benefits are omitted from the analysis.
- Because of the limited scope of the benefit analysis, all possible direct benefits (e.g., visibility benefits, reduced soiling, and materials damages to the commercial sector and some manufacturing industries) associated with emissions controls have not been estimated, while, in principle, all potentially significant direct costs associated with the alternative standards are included in the estimates.
- Distinctions between particle sizes are not made in the benefit analysis. The emissions control options selected in the cost analysis, however, do depend on particle size differences.

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* For a discussion of this issue, see R. C. Lind _et al_. (6).

The first two of the inconsistencies listed above tend to cause an overstatement of the incremental costs relative to the incremental benefits associated with the alternative PM NAAQS. The implications of the third inconsistency, however, are less straightforward and deserve additional comment.

Most of the studies used to estimate health effects are based on TSP measures of air quality. As a result, the benefit analysis cannot distinguish between effects caused by different particle sizes. The benefits associated with the alternative PM10 standards are estimated based on the estimated TSP concentration levels associated with PM10 controls. Evidence cited in the EPA/OAQPS Staff Paper, however, suggests that the PM10 fraction of TSP is primarily responsible for adverse health effects.

It is expected that PM10 controls will reduce both TSP and PM10 concentration levels. If PM10 controls reduce the PM10 fraction of TSP, the estimated benefits associated with the alternative PM10 standards might be understated relative to those associated with the TSP alternatives. An analysis was conducted of the predicted air quality associated with several standards. This analysis suggests that the average fraction of PM10 in TSP will remain virtually unchanged after controls are implemented, both for PM10 and TSP control strategies.* This result, however, should be interpreted in view of the limitations of the methods and data employed to select emissions control options and to project future air quality levels.

Later in this section, comparisons between the alternative PM10 and TSP standards are offered. These comparisons are based on approximate differences in the stringency of standards (in terms of TSP) and not differences in particle sizes. It is also noted that the estimated incremental net benefits associated with PM10 standards might be understated relative to those for the TSP standards, if PM10 control options are more effective than TSP control options in reducing the PM10 fraction of TSP.

* See Section 1 for a more detailed discussion.

LIMITATIONS AND QUALIFICATIONS OF BENEFIT-COST ANALYSIS

The preceding discussion in this section provides the necessary background for an interpretation of the benefit-cost analyses that follow. Before the results of these analyses are reported, however, it is appropriate to review some of the limitations of this approach as a means of evaluating the relative desirability of the alternative PM NAAQS.

Many of the shortcomings of benefit-cost analysis have already been described in the preceding text. A more complete list is as follows:

- The distributive or equity impacts of the alternative PM NAAQS are not evaluated within the framework of the benefit-cost analyses.
- The benefit-cost analyses rely on the validity and scope of estimates of benefits and costs.
- The benefit-cost analyses are limited in scope to an evaluation of a limited set of ambient air quality standards.
- The feasibility of the alternative PM NAAQS has not been determined.

Each of these points is discussed briefly below.

It has already been noted that the air quality standards will have different impacts on members of society; those who enjoy the benefits of the standards will not always be the same as those who bear the costs. The benefit-cost analyses conducted in this study do not evaluate these distributive or equity impacts. These impacts are described through a separate analysis. However, no judgment on the relative desirability of these distributive impacts is offered.

The results of the benefit-cost analyses depend, of course, on the validity and scope of the estimates of both benefits and costs associated with the alternative ambient air quality standards. The wide range of variability in the estimated benefits associated with each air quality standard have already been described. Similarly, all costs associated with the alternative PM NAAQS cannot be estimated with certainty. In some cases, the definitions of both benefits and costs employed in the estimates do not correspond exactly to the conceptually correct definitions. Finally, the benefit and cost estimates are limited in scope in that they do not include all possible benefits and costs (e.g., indirect costs) that may result from the alternative PM NAAQS.

The benefit-cost analyses described in this section are limited in scope in that they consider only a limited selection of possible PM NAAQS. As a result, the benefit-cost analysis will identify, with uncertainty, only the most efficient PM NAAQS among those considered. The identification of the most efficient possible standard requires an evaluation of all possible PM NAAQS.

Even if a standard is efficient, it might not be associated with an economically desirable allocation of resources if total costs exceed total benefits. The feasibility of the alternative PM NAAQS has not been comprehensively evaluated because estimates of the benefits associated with baseline controls are unavailable. Sufficient tests for feasibility, which assume that no benefits are associated with baseline emissions controls, yield generally inconclusive results.

The results of the benefit-cost analyses that follows should be interpreted in light of these limitations. Specifically, these analyses provide a qualified assessment of the cost-effectiveness and relative economic efficiency of the alternative PM NAAQS considered.

BENEFIT-COST ANALYSIS OF ALTERNATIVE PM NAAQS

The results of the benefit-cost analyses of the alternative PM NAAQS are reported below in this subsection. The cost-effectiveness and relative efficiency of each standard is determined through an analysis of the incremental benefits and incremental costs associated with the alternative PM

NAAQS. Finally, the distributive or equity impacts of these air quality standards are described.

Benefit-Cost Analysis: Incremental Net Benefits

The results of the analyses of the cost-effectiveness and relative economic efficiency of the alternative PM NAAQS are described below. Both analyses are conducted under each of the six benefit aggregation procedures. The six aggregation procedures and the studies included in them are described in Section 1. Briefly, these aggregation procedures are:

- Procedure A. Only quantitative studies approved by CASAC (Mazumdar *et al.* and Ferris *et al.*) are used to estimate benefits under this aggregation procedure. Estimates of nonhealth benefits are not included. Double counting of benefits is unlikely.

- Procedure B. This aggregation procedure includes estimates of benefits due to reduced acute morbidity (Samet *et al.*) in addition to benefit estimates included in Procedure A. Consequently, estimates of nonhealth benefits are not included and double counting of benefits is unlikely.

- Procedure C. The Samet *et al.* study is replaced by the Ostro study for use in estimating benefits attributable to reduced acute morbidity. This aggregation procedure also includes benefits estimated by the Mathtech study of household soiling effects. Coverage of all benefit categories is still incomplete. Double counting of benefits is unlikely.

- Procedure D. Studies by Lave and Seskin and by Lipfert are used to estimate benefits associated with reduced mortality instead of the Mazumdar *et al.* study. Otherwise, this procedure is identical to Procedure C.

- Procedure E. The Ferris *et al.* study is replaced by the Crocker *et al.* study for use in estimating benefits in the chronic morbidity category. Expanded coverage is given to household soiling and materials damage effects. A Mathtech study of soiling and materials damage in parts of the manufacturing sector is also included. Otherwise, this procedure is the same as Procedure D.

- Procedure F. This aggregation procedure includes the Mazumdar *et al.* study in addition to the studies by Lave and Seskin and by Lipfert for use in estimating benefits in the mortality category. Both the Ostro and the Samet et al. studies are used in the acute morbidity category and the Crocker et al. study is used in the chronic morbidity category. Studies by Watson and Jaksch, and Cummings et al. are used for household soiling and damage effects. The Mathtech study is used to estimate benefits due to reduced soiling and materials damage for part of the manufacturing sector. Some double counting of benefits among the subset for which estimates are provided is likely under this aggregation procedure.

Results are also reported for analyses conducted with and without the imposition of the Staff Paper* lower bound and for full (B Scenario) and partial (A Scenario) attainment states.

Comparisons of the alternative PM10 and TSP standards are provided below. Recall that these comparisons are based on TSP stringency and not particle sizes. Because of issues related to particle size differences, a second evaluation of only alternative PM10 standards is also provided.

Cost Effectiveness: Dominant and Inferior Options —

It is convenient to identify inferior air quality standards prior to conducting the efficiency tests. Recall that an inferior standard requires higher costs to achieve the same or smaller benefits than a dominant alternative. Once inferior alternatives are identified, only those standards that are cost effective need be evaluated in terms of efficiency. The inferior options are identified in Tables 2-2 through 2-5. Of the 240 (i.e., 10 x 6 x 2 x 2) combinations of standards, aggregation procedures, attainment states, and Staff Paper lower-bound conditions, 118 are inferior.

Incremental Net Benefits —

The results of the incremental net benefit analysis are reported in Tables 2-2 through 2-5 and interpreted below. Any standard that yields

* The Staff Paper lower bound refers to the TSP annual arithmetic mean (AAM) 110 $\mu g/m^3$ constraint applied to health studies.

Table 2-2

INCREMENTAL NET BENEFITS FOR ALTERNATIVE PM10 AND TSP STANDARDS*
(B Scenarios)

Alternative Standard	Aggregation Procedure					
	A	B	C	D	E	F
PM10 70 AAM/250 24-hr. 7 yr.	0.29	1.6	12	23	38	51
PM10 55 AAM 7 yr.	-0.71	1.6	20	40	72	95
PM10 55 AAM/250 24-hr. 7 yr.	-0.75**	1.6**	20**	41**	72**	96**
PM10 55 AAM/200 24-hr. 7 yr.	-0.69**	1.7	20	42	74	98
PM10 55 AAM/150 24-hr. 7 yr.	-1.5**	1.4**	24**	49**	87**	120**
PM10 48 AAM/183 24-hr. 7 yr.	-1.3**	1.8**	25**	53**	95**	130**
TSP 75 AGM/260 24-hr. 7 yr.	-0.48	2.6	27	54	98	130
TSP -/150 24-hr. 7 yr.	-3.5**	0.45**	30**	65**	120**	160**
TSP 75 AGM/260 24-hr. 9 yr.	-1.1	3.2	37	77	140	180
TSP -/150 24-hr. 9 yr.	-5.6	-0.09	41	91	160	220

* 1982 discounted present values in billions of 1980 dollars at a 10 percent discount rate. Time horizons for 7- and 9-year standards are, respectively, 1989-1995 and 1987-1995. Comparisons between PM10 and TSP standards are in terms of TSP stringency, not particle sizes.

** These options are inferior. Other options provide the same or larger incremental benefits at lower incremental cost.

Table 2-3

INCREMENTAL NET BENEFITS FOR ALTERNATIVE PM10 AND TSP STANDARDS*
(A Scenarios)

Alternative Standard	Aggregation Procedure					
	A	B	C	D	E	F
PM10 70 AAM/250 24-hr. 7 yr.	0.38	1.2	7.7	15	23	32
PM10 55 AAM 7 yr.	0.20	1.4	11	21	34	46
PM10 55 AAM/250 24-hr. 7 yr.	0.18**	1.4**	11**	21**	34**	46**
PM10 55 AAM/200 24-hr. 7 yr.	0.18**	1.5	11	22	35	48
PM10 55 AAM/150 24-hr. 7 yr.	-0.03**	1.5**	13**	25**	41**	57**
PM10 48 AAM/183 24-hr. 7 yr.	-0.08**	1.4**	13**	25**	42**	57**
TSP 75 AGM/260 24-hr. 7 yr.	0.16	1.7	13	26	43	59
TSP -/150 24-hr. 7 yr.	-0.38**	1.6**	16**	32**	54**	74**
TSP 75 AGM/260 24-hr. 9 yr.	0.11	2.2	18	37	60	83
TSP -/150 24-hr. 9 yr.	-0.69	2.1	22	45	76	100

* 1982 discounted present values in billions of 1980 dollars at a 10 percent discount rate. Time horizons for 7- and 9-year standards are, respectively, 1989-1995 and 1987-1995. Comparisons between PM10 and TSP standards are in terms of TSP stringency, not particle sizes.

** These options are inferior. Other options provide the same or larger incremental benefits at lower incremental cost.

Table 2-4

INCREMENTAL NET BENEFITS FOR ALTERNATIVE PM10 AND TSP STANDARDS WITH LOWER BOUND APPLIED*
(B Scenarios)

Alternative Standard	Aggregation Procedure					
	A	B	C	D	E	F
PM10 70 AAM/250 24-hr. 7 yr.	-0.51	-0.33	1.7	13	28	39
PM10 55 AAM 7 yr.	-2.1	-1.9	0.8	16	38	58
PM10 55 AAM/250 24-hr. 7 yr.	-2.1**	-1.9**	0.76**	16**	38**	59**
PM10 55 AAM/200 24-hr. 7 yr.	-2.1**	-1.9**	0.83	16**	38**	59
PM10 55 AAM/150 24-hr. 7 yr.	-3.1**	-2.9**	0.12**	15**	39**	65**
PM10 48 AAM/183 24-hr. 7 yr.	-2.9**	-2.7**	0.39**	16**	40**	68**
TSP 75 AGM/260 24-hr. 7 yr.	-2.2**	-2.0**	1.2	16**	41	69
TSP -/150 24-hr. 7 yr.	-5.5**	-5.3**	-1.7**	14**	41**	78**
TSP 75 AGM/260 24-hr. 9 yr.	-3.5	-3.2	0.97	22	56	95
TSP -/150 24-hr. 9 yr.	-8.4	-8.1**	-3.2	18	55	110

* 1982 discounted present values in billions of 1980 dollars at a 10 percent discount rate. Time horizons for 7- and 9-year standards are, respectively, 1989-1995 and 1987-1995. The TSP AAM lower bound of 110 $\mu g/m^3$ is applied to all health studies. Comparisons between PM10 and TSP standards are in terms of TSP stringency, not particle sizes.

** These options are inferior. Other options provide the same or larger incremental benefits at lower incremental cost.

Table 2-5

INCREMENTAL NET BENEFITS FOR ALTERNATIVE PM10 AND TSP STANDARDS WITH LOWER BOUND APPLIED*
(A Scenarios)

Alternative Standard	Aggregation Procedure					
	A	B	C	D	E	F
PM10 70 AAM/250 24-hr. 7 yr.	-0.16	-0.03	1.3	8.8	17	24
PM10 55 AAM 7 yr.	-0.56**	-0.43**	1.1	9.7	20	30
PM10 55 AAM/250 24-hr. 7 yr.	-0.59**	-0.46**	1.0**	9.6**	20**	30**
PM10 55 AAM/200 24-hr. 7 yr.	-0.61**	-0.48**	1.1**	9.6**	20	31**
PM10 55 AAM/150 24-hr. 7 yr.	-0.92**	-0.79**	0.87**	9.5**	20	33**
PM10 48 AAM/183 24-hr. 7 yr.	-0.98**	-0.85**	0.80**	9.4**	20**	34**
TSP 75 AGM/260 24-hr. 7 yr.	-0.74**	-0.61**	1.1	9.6**	20**	34
TSP -/150 24-hr. 7 yr.	-1.4**	-1.3**	0.60**	9.3**	22**	39**
TSP 75 AGM/260 24-hr. 9 yr.	-1.2	-1.0	1.3	13	28	47
TSP -/150 24-hr. 9 yr.	-2.2**	-2.0**	0.60	13	30	55

* 1982 discounted present values in billions of 1980 dollars at a 10 percent discount rate. Time horizons for 7- and 9-year standards are, respectively, 1989-1995 and 1987-1995. The TSP AAM lower bound of 110 $\mu g/m^3$ is applied to all health studies. Comparisons between PM10 and TSP standards are in terms of TSP stringency, not particle sizes.

** These options are inferior. Other options provide the same or larger incremental benefits at lower incremental cost.

positive incremental net benefits will produce an improvement in the efficiency of resource allocation relative to baseline controls. Alternatively, a standard associated with negative incremental net benefits will produce an inefficient allocation of resources relative to baseline controls. The standard generating the largest incremental net benefits is the most efficient of the alternative standards evaluated.

The figures presented in Tables 2-2 and 2-3 represent estimates of incremental net benefits corresponding to the full and partial attainment scenarios (scenarios B and A), respectively, when no lower bounds are applied to the health studies.* Comparable estimates when the Staff Paper lower bounds are applied are reported in Tables 2-4 and 2-5 for each of the two attainment scenarios.** The results reported in these latter two tables should be interpreted in view of the comments offered in Sections 1 and 10 regarding the application of the lower-bound concentration levels to health studies. Similarly, estimates of incremental net benefits for the B scenarios should be interpreted in view of the uncertainty in the estimated costs of achieving full attainment.

The results of the incremental net benefit analysis shed light on three important issues regarding the alternative PM NAAQS. These issues are:

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* The figures reported in Table 2-2 are computed as the difference between the incremental benefits reported earlier in Table 1-11 and the incremental costs for the B scenario reported in Table 2-1. Comparable figures in Table 2-3 are computed as the difference between estimated incremental benefits in Table 1-12 and the incremental costs for the A scenario in Table 2-1. The estimated incremental net benefits reported in Tables 2-2 and 2-3 have been rounded to two significant digits.

** Net incremental benefits reported in Table 2-4 are computed as the difference between the incremental benefits reported in Table 1-13 and the B scenario costs reported in Table 2-1. The figures in Table 2-5 are computed in the same fashion, except that incremental benefits reported in Table 1-14 and A scenario costs reported in Table 2-1 are used. The estimated incremental net benefits reported in Tables 2-4 and 2-5 have been rounded to two significant digits.

- The relative economic efficiency of the alternative standards.
- The economic efficiency of complete versus partial attainment.
- The economic efficiency of the implementation periods for the TSP options.

Some conclusions regarding each of these issues are provided immediately below. These findings, however, should be interpreted in view of the previously mentioned caveats regarding benefit-cost analyses.

Economic Efficiency of Alternative Standards —

The estimated incremental net benefits associated with the alternative PM NAAQS are sensitive to the aggregation procedures employed, the attainment status considered, and the application of lower bounds to the health studies. A general understanding of how these three conditions affect estimated incremental net benefits is helpful in evaluating the economic efficiency of specific alternative standards.

Other things being the same, the estimated incremental benefits associated with a given standard increase as more comprehensive aggregation procedures are applied. The estimated costs associated with a given standard, however, remain constant across aggregation procedures. Consequently, the estimated incremental net benefits associated with all standards increase as more comprehensive aggregation procedures are employed. It is also noteworthy that, ceteris paribus, the estimated incremental net benefits associated with more stringent standards typically increase relative to those associated with less stringent standards as more comprehensive aggregation procedures are applied.

The estimated incremental net benefits under the full attainment scenario (B) are usually higher than those estimated under the partial attainment scenario (A), other things being the same. This general observation, however, consistently does not hold for aggregation procedure A.

This occurs because the functional forms used in the studies included in aggregation procedure A predict diminishing marginal benefits to incremental air quality improvements over certain concentration ranges.

The application of the Staff Paper lower bound TSP annual arithmetic mean (AAM) concentration to health studies has the general effect of reducing the estimated incremental benefits associated with all standards, other things being the same. Since estimated costs do not depend on the lower bound, estimated net incremental benefits naturally decrease when the lower bound is applied. Moreover, for a given aggregation procedure and attainment status, the application of the lower bound has the typical effect of increasing the estimated economic efficiency of less stringent standards relative to more stringent standards.

Given the general effects of aggregation procedures, attainment status, and the application of the lower bound on estimated incremental net benefits, the evaluations of the relative economic efficiency of specific standards are more straightforward. Specifically, three alternative standards -- the two TSP 9-year standards and the PM10 70 AAM/250 24-hour standard -- stand out as being most efficient when the standards are compared based on TSP stringency. Typically, the TSP standards are preferred (based on the comparison of TSP stringency) when more comprehensive aggregation procedures are applied, while the PM10 70 AAM/250 24-hour standard is generally preferred when less comprehensive aggregation procedures are employed, the lower bound is applied, and only partial attainment is achieved.

The domain of economically preferred air quality standards is displayed in Table 2-6. The most efficient standard (i.e., the standard associated with the largest positive estimated incremental net benefits) is indicated for each of the several conditions under which incremental net benefits are estimated.

As Table 2-6 indicates, none of the alternative PM NAAQS considered is efficient when incremental net benefits are estimated with the TSP AAM

Table 2-6

DOMAIN OF ECONOMICALLY PREFERRED STANDARDS*

Conditions	Aggregation Procedure					
	A	B	C	D	E	F
WITH LOWER BOUND: Partial Attainment (Scenario A)	No Standard Efficient	No Standard Efficient	PM10 70/250 or TSP 75/260	TSP 75/260 or TSP 150	TSP 150	TSP 150
WITH LOWER BOUND: Complete Attainment (Scenario B)	No Standard Efficient	No Standard Efficient	PM10 70/250	TSP 75/260	TSP 75/260	TSP 150
WITHOUT LOWER BOUND: Partial Attainment (Scenario A)	PM10 70/250	TSP 75/260	TSP 150	TSP 150	TSP 150	TSP 150
WITHOUT LOWER BOUND: Complete Attainment (Scenario B)	PM10 70/250	TSP 75/260	TSP 150	TSP 150	TSP 150	TSP 150

* All preferred TSP standards identified are 9-year standards with the 1987-1995 time horizon. Conditions "with lower bound" refer to cases in which the TSP AAM lower bound of 110 $\mu g/m^3$ is applied to all health studies. Comparisons between PM10 and TSP standards are in terms of TSP stringency, not particle sizes.

lower bound applied and under aggregation procedures A and B, regardless of attainment status. In these cases, estimated incremental net benefits are negative for all standards evaluated. A literal interpretation of the estimates indicates that all considered standards are less efficient than baseline controls.

When estimated incremental net benefits are computed under the same conditions, except without applying the lower bound, the PM10 70/250 standard is the most efficient standard under aggregation procedure A, while the TSP 75/260 9-year standard is most efficient in terms of TSP stringency under aggregation procedure B. Both conclusions hold regardless of attainment status.

Under aggregation procedure C, the PM10 70/250 standard is the most efficient of all considered standards for the complete attainment scenario, and is tied with the 9-year TSP 75/260 standard under partial attainment if benefits are computed while applying the lower bound to all health studies. The TSP 150 9-year standard, however, is the economically preferred option under aggregation procedure C when benefits are estimated without the lower bound.

The two TSP standards are preferred under aggregation procedures D through F, regardless of attainment status and the application of the lower bound. The TSP 150 standard is the most efficient of standards considered, except in procedure D when incremental net benefits are estimated with the lower bound applied, and in procedure E with the lower bound applied and under the complete attainment scenario. The TSP 75/260 standard is preferred or equally efficient in these exceptions.

All of the comparisons between alternative PM10 and TSP standards described above are based on TSP stringency and not particle sizes. The estimated incremental net benefits associated with the alternative PM10 standards might be understated relative to those associated with the TSP standards if PM10 control options are more effective than TSP control options in reducing the PM10 fraction of TSP. If only the alternative PM10 standards are evaluated for efficiency, the PM10 48 AAM/183 24-hour standard usually replaces the two TSP standards as being economically preferred.* The following cases are exceptions:

- Either the PM10 55 AAM/200 or the PM10 55 AAM/150 standard is preferred when incremental net benefits are computed under partial attainment (A scenario) without applying the Staff Paper lower bound for aggregation procedure B.

- The PM10 55 AAM standard is preferred when incremental net benefits are computed under partial attainment and with the application of the lower bound for aggregation procedure D.

There are also some cases in which other less stringent PM10 standards have the same estimated incremental net benefits as the PM10 48 AAM/183 standard. The benefit-cost analysis cannot generally make distinctions between the economic efficiency of alternative standards with the same estimated incremental net benefits.

It is noteworthy that the intermediate (in terms of stringency) air quality standards are generally not preferred, based on the analysis of incremental net benefits. The least stringent standard, the PM10 70 AAM/250 24-hour standard, is usually preferred when relatively restrictive assumptions are imposed on the estimated benefits. However, the most stringent standards are usually most efficient when less restrictive assumptions are imposed on estimated benefits. These two results typically hold, regardless of whether all alternatives or only PM10 alternatives are considered.

When the standards which yield the highest net incremental benefit are the least or most restrictive considered, it is desirable to evaluate a wider range of alternative standards. Specifically, in cases where PM10 70/250 is preferred, more lenient alternatives should be examined to

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* Tables 2-2 through 2-5 indicate that the PM10 48 AAM/183 standard is inferior. The results of the cost-effectiveness analyses reported in these tables, however, include the alternative TSP standards.

determine if incremental net benefits peak at 70/250, or whether they would be larger with a less stringent standard. In cases where TSP 150 (or the PM10 48 AAM/183) standard is preferred, more stringent alternative standards should be examined to see if incremental net benefits peak, or if some more stringent standard is economically preferred.

The identification of the most efficient option is far more sensitive to the application of aggregation procedures than to either the attainment status or the application of the Staff Paper lower bound. Under aggregation procedure A (the least comprehensive aggregation procedure), the PM10 70 AAM/250 24-hour standard is always preferred among the standards evaluated. In contrast, the two 9-year TSP standards are always most efficient when alternative PM10 and TSP standards are compared in terms of TSP stringency under aggregation procedures D through F.

As noted earlier in this section, applied benefit-cost analysis typically can provide only a qualified economic assessment of regulatory alternatives. The previously noted caveats regarding benefit, cost, and air quality estimates as inputs to the analysis should be considered in using the estimated incremental net benefits to assess the relative efficiency of the alternative PM NAAQS. First, in order to determine if a given standard is efficient (i.e., relative to the baseline scenario), the positive difference between estimated incremental benefits and costs should be statistically significant. Second, in order to identify the most efficient standard (among those evaluated), the difference between estimated incremental net benefits for the preferred and next best standard should also be statistically significant. However, because some of the uncertainty in the estimated incremental benefits and costs cannot be measured, no statistical tests have been conducted. It is noted that differences in estimated incremental net benefits become greater, both in absolute and relative terms, as more comprehensive aggregation schemes are employed. These differences, however, do not imply the presence or the absence of statistical significance.

Economic Efficiency: Attainment Status and TSP Implementation Periods —

Based on the results of the benefit-cost analysis, complete attainment is generally preferred to partial attainment because, other things being equal, estimated incremental net benefits are larger under the B scenario. Partial attainment is preferred for all efficient standards evaluated, however, if aggregation procedure A is adopted. These conclusions depend on the accuracy of the estimates of the differential cost associated with complete attainment. As noted previously, these cost estimates are highly uncertain.

The results of the analyses also suggest that the 9-year implementation period for the TSP standards are associated with higher incremental net benefits than the 7-year implementation period. Although there are some conditions under which the estimated incremental net benefits are larger for the 7-year standards than the 9-year standards, the issue of the implementation period is moot in these cases because the TSP standards are not efficient relative to the PM10 standards. That is, in those cases in which the TSP standards are ranked as being more efficient than the PM10 standards, the 9-year implementation period is always more efficient than the shorter period.

These conclusions imply the ability to measure statistically significant differences in benefits and costs. As was the case for the analysis of the relative efficiency of specific standards, differences in estimated incremental benefits and costs become greater as more comprehensive aggregation procedures are applied. However, the earlier caveat applies here as well: relatively large differences do not imply statistically significant differences; smaller differences do not necessarily imply the absence of statistical significance.

Distribution of Incremental Net Benefits

As was discussed earlier, the benefit-cost analyses are employed to assess the economic effects of a given PM NAAQS on resource allocation within the economy. For purposes of this analysis, it is assumed that those who benefit from a given PM NAAQS can potentially compensate those who incur the costs of this PM NAAQS, and still retain some welfare gain. However, full compensation is not actually paid, so that some individuals will be worse off. In order to evaluate the full effect of a particular standard on economic welfare, judgments must be made regarding the desirability of the distribution of benefits and costs associated with the implementation of a given PM NAAQS. These judgments are not made within the context of the benefit-cost analyses; rather, they are described below. In particular, the following distributional issues are considered:

- Net benefits across regions.
- The sectoral distribution of impacts -- i.e., the distributions across and within industries.

Regional Distribution —

It is not likely that net benefits associated with any given PM NAAQS are distributed equally over the entire United States. Thus, data on the distribution of benefits and costs can provide additional information regarding the impacts of the alternative PM NAAQS.

The method employed to estimate the incremental control costs did not permit a consistent estimation of costs by region for the complete attainment scenario (i.e., the B scenario). However, incremental control costs by region are available when residual nonattainment is permitted (i.e., for the A scenario). Estimates of the incremental net benefits associated with this scenario are calculated for the PM10 70 AAM/250 24-hour standard across each of several regions for each of the six aggregation procedures. The regional distribution for this standard is presented in Table 2-7, where the incremental net benefits are reported by EPA administrative region. The comparable distribution when the TSP AAM lower bound of 110 $\mu g/m^3$ is applied to all health studies is reported in Table 2-8.

Table 2-7

INCREMENTAL NET BENEFITS BY REGION FOR THE PM10 (70, 250) SCENARIO A STANDARD*

EPA Region	Aggregation Procedure					
	A	B	C	D	E	F
I New England	0.0	0.0	0.0	0.0	0.0	0.0
II New York-New Jersey	0.0	0.0	0.02	0.04	0.06	0.08
III Middle Atlantic	0.07	0.13	0.60	1.0	1.8	2.4
IV South Atlantic	0.0	0.06	0.52	1.0	1.7	2.2
V East North Central	-0.05	0.24	2.5	5.7	8.6	11
VI South Central	0.01	0.11	0.83	1.8	2.7	3.7
VII Midwest	0.01	0.03	0.17	0.35	0.55	0.74
VIII Mountain	0.0	0.05	0.39	0.74	1.3	1.8
IX South Pacific	0.33	0.59	2.5	4.2	6.3	8.9
X North Pacific	0.01	0.03	0.21	0.38	0.58	0.81
U.S.	0.38	1.2	7.7	15	23	32

* 1982 discounted present values in billions of 1980 dollars at a 7-year time horizon (1989-95) and a 10 percent discount rate. Regional incremental net benefits may not sum to U.S. totals due to independent rounding.

Sources: Regional incremental benefits, Section 11, Table 11-22; regional incremental costs, Reference (5). Costs have been adjusted to reflect the 9-year implementation horizon, and AME costs at 4 percent have been added.

Table 2-8

INCREMENTAL NET BENEFITS BY REGION FOR THE PM10 (70, 250) SCENARIO A STANDARD WITH LOWER BOUND APPLIED*

EPA Region	Aggregation Procedure					
	A	B	C	D	E	F
I New England	0.0	0.0	0.0	0.0	0.0	0.0
II New York-New Jersey	0.0	0.0	0.0	0.0	0.01	0.03
III Middle Atlantic	-0.01	-0.01	0.03	0.53	1.3	1.8
IV South Atlantic	-0.05	-0.05	0.0	0.51	1.1	1.6
V East North Central	-0.24	-0.24	-0.05	3.3	6.1	8.4
VI South Central	-0.05	-0.05	0.0	0.95	1.8	2.6
VII Midwest	-0.01	-0.01	0.0	0.18	0.37	0.53
VIII Mountain	-0.02	0.0	0.13	0.35	0.72	1.2
IX South Pacific	0.22	0.33	1.2	3.0	5.0	7.4
X North Pacific	-0.01	-0.01	0.02	0.16	0.30	0.48
U.S.	-0.16	-0.03	1.3	8.9	17	24

* 1982 discounted present values in billions of 1980 dollars at a 7-year time horizon (1989-95) and a 10 percent discount rate. The TSP AAM lower bound of 110 $\mu g/m^3$ is applied to all health studies. Regional incremental net benefits may not sum to U.S. totals due to independent rounding.

Sources: Regional incremental benefits, Section 11, Table 11-62; regional incremental costs, Reference (5). Costs have been adjusted to reflect the 9-year implementation horizon, and AME costs at 4 percent have been added.

The regional distribution of estimated incremental net benefits does vary somewhat across aggregation procedures, but generally, the largest shares of incremental net benefits are realized by East North Central and South Pacific regions. For example, the estimates reported in Table 2-7 indicate that about 65 percent of the incremental net benefits for the PM10 standard accrue to these two regions when aggregation procedure E is applied. The figure is also about 65 percent under procedure E, when the lower bound is applied as in Table 2-8. As noted above, this result assumes that not all counties are in complete attainment with the standard. Consequently, this distribution cannot be used to make any inferences regarding the distribution of net benefits when the condition of full attainment is applied.

The behavior of the regional distribution of incremental net benefits associated with more stringent air quality standards may also be of interest. Regional distributions of estimated incremental net benefits for the TSP 75 AGM/260 9-year standard are reported in Tables 2-9 and 2-10, respectively, when incremental net benefits are computed without and with the TSP AAM lower-bound. The results indicate a slightly more even regional distribution of incremental net benefits compared to the distribution associated with the more lenient PM10 standard. For example, the East North Central and South Pacific regions receive only about 52 percent or 63 percent of total estimated incremental net benefits under aggregation procedure E, depending on whether incremental net benefits are computed without or with the Staff Paper lower-bound concentration level.

Sectoral Distribution —

Incremental net benefits associated with alternative PM NAAQS are also distributed over various economic sectors. For example, benefits and/or costs may accrue in the household, manufacturing, commercial, institutional, and government sectors. In this analysis, benefit estimates are limited to the household sector and a small subset of the manufacturing sector, while estimates of control costs include costs borne by private industrial sources and government-owned utilities and roads. Thus, a

Table 2-9

INCREMENTAL NET BENEFITS BY REGION FOR THE TSP (75, 260) 9-YEAR SCENARIO A STANDARD*

EPA Region	Aggregation Procedure					
	A	B	C	D	E	F
I New England	0.0	0.05	0.41	0.80	1.4	2.0
II New York-New Jersey	-0.01	0.03	0.37	0.85	1.6	2.1
III Middle Atlantic	-0.03	0.20	1.9	3.7	6.6	9.1
IV South Atlantic	-0.09	0.10	1.6	3.1	5.4	7.4
V East North Central	-0.24	0.44	5.6	12	20	27
VI South Central	0.02	0.22	1.6	3.5	5.6	7.7
VII Midwest	-0.01	0.10	0.92	1.8	3.0	4.2
VIII Mountain	-0.02	0.09	0.92	1.7	2.9	4.1
IX South Pacific	0.48	0.92	4.2	7.2	11	16
X North Pacific	0.01	0.09	0.75	1.5	2.5	3.4
U.S.	0.11	2.2	18	37	60	83

* 1982 discounted present values in billions of 1980 dollars at a 9-year time horizon (1989-95) and a 10 percent discount rate. Regional incremental net benefits may not sum to U.S. totals due to independent rounding.

Sources: Regional incremental benefits, Section 11, Table 11-38; regional incremental costs, Reference (5). Costs have been adjusted to reflect the 9-year implementation horizon, and AME costs at 4 percent have been added.

Table 2-10

INCREMENTAL NET BENEFITS BY REGION FOR THE TSP (75, 260) SCENARIO A STANDARD WITH LOWER BOUND APPLIED*

EPA Region	Aggregation Procedure					
	A	B	C	D	E	F
I New England	-0.02	-0.02	0.0	0.04	0.22	0.68
II New York-New Jersey	-0.03	-0.03	0.0	0.13	0.49	0.95
III Middle Atlantic	-0.23	-0.23	-0.11	0.91	2.7	4.7
IV South Atlantic	-0.21	-0.20	-0.11	0.72	1.9	3.7
V East North Central	-0.65	-0.65	-0.24	4.8	9.9	16
VI South Central	-0.07	-0.07	0.03	1.4	2.9	4.6
VII Midwest	-0.08	-0.08	-0.03	0.27	0.79	1.8
VIII Mountain	-0.08	-0.06	0.11	0.45	1.1	2.1
IX South Pacific	0.24	0.39	1.6	4.3	7.6	12
X North Pacific	-0.04	-0.04	0.03	0.27	0.64	1.4
U.S.	-1.2	-1.0	1.3	13	28	47

* 1982 discounted present values in billions of 1980 dollars at a 9-year time horizon (1989-95) and a 10 percent discount rate. The TSP AAM lower bound of 110 $\mu g/m^3$ is applied to all health studies. Regional incremental net benefits may not sum to U.S. totals due to independent rounding.

Sources: Regional incremental benefits, Section 11, Table 11-78; regional incremental costs, Reference (5). Costs have been adjusted to reflect the 9-year implementation horizon, and AME costs at 4 percent have been added.

complete analysis of the distribution of net incremental benefits by sector is not possible. However, the results of the Economic Impact Analysis (EIA) do provide some information on the distribution of estimated control costs by economic sector (1).

Estimated direct emissions control costs are summarized by 2- and 4-digit SIC codes in Table 2-11 for the 9-year TSP 75/260 standard under the partial attainment scenario (estimated costs by industry are unavailable for the complete attainment scenario). For most industries, the estimated control costs associated with less stringent standards are lower than those associated with the 9-year TSP 75/260 standard under the partial attainment scenario. The estimated control costs for the complete attainment scenario, however, are highly uncertain and much larger than those associated with partial attainment. Consequently, the adverse impacts on some industries could be more severe under complete attainment.

A high percentage of emissions control costs will be shared by the manufacturing (SIC 20-39) and utility (SIC 49) sectors. The manufacturing sector, for example, accounts for about 50 percent of all capital expenditures under the TSP 75/260 standard. The utility sector will incur about 44 percent of estimated capital costs under this standard. Electric utilities (SIC 4911) are expected to bear about 40 percent of total capital costs.

The EIA uses the estimates of control costs to assess the adverse impacts of the most restrictive standard (i.e., the current TSP combined primary and secondary standards) on production, prices, plant closures, and employment. The analysis includes 16 industries judged to be most seriously affected by the current TSP standards. Each industry is analyzed separately. Consequently, the effects in factor and output markets between and among these industries are ignored. In addition, the EIA does not consider possible positive economic impacts such as employment gains in the pollution control equipment industry or gains due to innovation-inducing effects of the regulations. However, the EIA does provide information which is useful in describing the distribution of several economic effects

Table 2-11

CAPITAL AND AFTER-TAX ANNUALIZED COSTS (ATAC) OF CONTROL, BY INDUSTRY, FOR THE TSP (75, 260) 9-YEAR STANDARD*
(Scenario A)

SIC**	Capital Cost	ATAC	SIC**	Capital Cost	ATAC
02	1.91	0.193	34	27.2	3.19
07	0.400	0.042	35	8.65	0.999
08	0.008	0.001	36	8.16	0.888
10	10.7	1.37	37	39.4	4.20
14	61.2	9.92	38	6.84	0.755
1422	20.2	3.66	39	6.29	0.787
1429	5.2	0.870	40	1.41	1.28
1442	5.68	1.40	42	6.40	0.892
16		0.125	44	0.214	0.022
20	103	11.1	49	1,130	120
2041	45.6	4.64	4911	1,020	108
21	2.11	0.220	4961	65.5	7.60
22	5.51	0.632	50	1.06	0.313
24	1.67	0.424	51	42.7	5.11
25	0.816	0.091	52	0.414	0.071
26	67.0	7.87	53	0.230	0.024
27	2.30	0.250	65	1.14	0.149
28	71.4	8.11	80	11.2	1.31
29	73.2	11.9	82	10.4	1.10
2951	36.6	7.27	91	2.65	0.325
30	0.764	0.090	92	0.727	0.080
32	186	23.6	93	1.43	0.150
3241	74.5	8.73	94	1.52	0.166
3274	21.2	2.58	95	0.391	0.046
3281	4.95	0.562	96	14.2	1.62
3295	51.4	6.87	97	2.64	0.301
33	623	72.4	99	45.5	8.86
3312	444	53.4			
3321	67.2	6.77			
3331	2.96	0.623			
3332		0.067			
3334	0.340	0.166	Total	2,580	301

* Millions of 1980 dollars. Individual entries may not sum to totals due to independent rounding.

** Sectors by SIC are: Agriculture (01-09); Mining (10-14); Construction (15-19); Manufacturing (20-39); Service Utilities (40-49); Wholesale Goods (50-59); Service Industries (80-89); Government Operations (90-99).

Source: Reference (1).

attributable to the current TSP standards. These effects are summarized below.

For each industry, the type and magnitude of economic effect depends, to a large extent, on the ability of firms within that industry to pass control costs through to other economic agents. In some instances, these agents may be firms in other industries. However, it is also possible that agents in the household, commercial, institutional, and governmental sectors may bear the costs that are passed through. On the basis of the EIA, it appears that most affected firms will absorb at least some of these costs. Hence, the effect of the current TSP standards on prices or output in the product markets of these firms will be mitigated. However, for some of the controlled firms, the cost increase they must absorb may force them to consider terminating operations.* While there will be some employee displacement effects associated with these closures, the EIA concludes that no net impact on industry employment or output is anticipated.

No significant foreign trade effects are anticipated for any of the 16 industries. The impact of current TSP standards on investment, productivity, and innovation within any of these industries is likely to be adverse but small. Finally, it should be noted that the economic impacts of less stringent PM NAAQS generally will be less severe, but those associated with full attainment could be much more severe.

CONCLUSIONS AND QUALIFICATIONS

The benefit-cost analyses reported earlier in this section were conducted to assess the cost-effectiveness and economic efficiency of the alternative standards. The economic efficiency of attainment states, and

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* Emissions control costs may force some establishments to close in the following industries: cement; crushed and broken stone; construction sand and gravel; paving mixtures and blocks; cut stone and stone products; crushed minerals and earths; grain and flour milling; and iron foundry. The number of expected closures in each of these industries, however, is a relatively small percent of total industry establishments.

the implementation periods for the TSP standards, were also evaluated. In addition, the distributional impacts associated with the alternative standards were described. The conclusions offered from the interpretation of these analyses, however, are subject to qualifications.

Conclusions

The major conclusions that emerge from the benefit-cost analyses are described briefly below for each of the several aspects of the alternative PM NAAQS that were evaluated.

Cost Effectiveness —

The analysis of cost effectiveness indicates that 118 of the 240 combinations are inferior (i.e., cost more to achieve the same or smaller benefits than other options).

Economic Efficiency of Alternative Standards —

The major conclusions regarding economic efficiency of alternative standards are as follows:

- The ranking of standards in terms of economic efficiency is especially sensitive to the different benefit aggregation procedures employed.
- Given the use of only CASAC-approved quantitative studies that are amenable to benefit analysis and the imposition of the Staff paper lower bound, none of the alternative standards is efficient. Given a literal interpretation of this result, an alternative less restrictive than the least restrictive considered alternative (PM10 70 AAM/250 24-hour expected value) is warranted in terms of economic efficiency.
- Given the use of the same CASAC-approved studies, but without imposing the lower-bound concentration level, the PM10 70 AAM/250 24-hour expected value alternative is preferred in terms of economic efficiency.

- Given the adoption of more comprehensive benefit aggregation procedures, the two 9-year TSP alternatives of 75 AGM/260 24-hour (second high) and 150 24-hour (second high) are preferred when all alternatives are compared in terms of TSP stringency.

- When only PM10 standards are evaluated for efficiency, the PM10 48 AAM/183 24-hour standard is usually preferred.

Economic Efficiency of Partial Versus Complete Attainment —

Two major conclusions result from the analysis of the economic efficiency of attainment status. These conclusions are:

- Given the use of only CASAC-approved quantitative studies which are amenable to the benefit analysis, partial attainment is preferred to full attainment.

- Given the use of more comprehensive benefit aggregation procedures, complete attainment is generally preferred to partial attainment.

However, these conclusions depend importantly on the method and data used to estimate the cost differential associated with complete attainment. As noted previously, these cost estimates are subject to considerable uncertainty.

Economic Efficiency of TSP Implementation Periods —

Alternative TSP standards were evaluated for both 7-year (1989-1995) and 9-year (1987-1995) implementation periods. The 9-year TSP implementation period is preferred in all cases in which either of the two TSP standards were ranked as most efficient of the alternative standards evaluated.

Distributional Impacts —

The distributional impacts of the alternative PM NAAQS are not evaluated by the benefit-cost analyses. These distributional impacts were described. Briefly summarizing, the following conclusions are offered:

- Based on the findings of the economic impact analysis, no major adverse impacts associated with the alternative standards are expected. This conclusion, however, is based on an analysis of estimated control costs under partial attainment. Estimates of costs under full attainment are much larger and highly uncertain. As a result, adverse impacts could be more severe under complete attainment.

- Under the less restrictive standards, much of the estimated incremental net benefits will be realized in the East North Central and South Pacific EPA administrative regions. Under the more stringent standards, these two regions receive a smaller but still considerable share of the estimated incremental net benefits. The regional distribution of incremental net benefits is based on the partial attainment scenario. The results of this analysis cannot be used to project regional distributions under complete attainment.

Qualifications

The general limitations of applied benefit-cost analysis and specific qualifications to this analysis have already been described in this section. The conclusions summarized immediately above should be assessed in full view of these limitations and qualifications. Some of the specific qualifications to this analysis are summarized briefly below.

The validity of the benefit-cost analyses depends on the estimates of benefits, costs, and air quality. Sources of potential biases and uncertainty in each of these estimates have already been described. It is noted that these biases and uncertainties do bear directly on the conclusions summarized above. These conclusions depend on the ability to detect meaningful differences between benefits and costs, and differences in net benefits across the alternative standards. As was stated previously, tests for statistically significant differences have not been conducted because not all of the uncertainty associated with the estimated benefits and costs is known.

In most cases, the alternative PM NAAQS ranked as most efficient are either the least or most stringent of the standards evaluated. Because of this, additional information on efficiency could have been obtained if a wider range of standards had been evaluated. However, the analysis was limited to options that were no less restrictive than the middle of the EPA Staff Paper range (i.e., PM 70 AAM/250 24-hour expected value) and no more restrictive than the current TSP secondary standard (150 24-hour second high).

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