FINAL

VOLUME I
THE BENEFITS OF AIR POLLUTION CONTROL IN CALIFORNIA

Reviewed and Approved

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THE BENEFITS OF AIR POLLUTION CONTROL IN CALIFORNIA

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ABSTRACT

The objective of this research was, to the degree possible, to provide quantitative estimates of economic measures of benefits (or damage) from controlling air pollution under alternative policy relevant scenarios. While it is important to recognize and discuss the conceptual and practical limitations in conducting such an analysis, the overriding focus of this effort was to use the best available literature, data, methods and professional judgement to estimate and represent as fully and accurately as possible the economic measures of air pollution control benefits.

The study encompasses four air basins in California that have a combined 1980 population of just over 19 million people (80 percent of the state total): the San Diego Air Basin, the South Coast Air Basin, the San Joaquin Valley Air Basin, and the San Francisco Bay Area Air Basin. For each alternative scenario, emission estimates of particulate matter, nitrogen oxides, sulfur oxides, lead, and reactive organic gases are made. These are used with modelling to estimate ambient concentrations of total suspended particulates, nitrogen dioxide, sulfur dioxide, sulfates, lead, ozone, and visibility conditions for 641 locations in the four air basins. Physical and economic measures of air pollution control benefits are calculated for five effects categories: human health, agriculture, materials and soiling, forests, and visibility aesthetics. The physical impacts and economic measures are based upon the best available literature and include a "best" estimate, a "lower bound" estimate, and an "upper bound" estimate. An assessment of the probable percentage of economic benefits for each effects category is also presented.

Five air pollution control scenario comparisons are examined. The first two compare actual conditions in 1979 to estimates of conditions that would have occurred in 1979 with 1) 1960 levels of control (called the 1979 no control comparison), and 2) with those controls that would have been undertaken even without air pollution control regulations (called the 1979 prevailing practice comparison). The last three comparisons relate predicted conditions in 1987 under planned controls with estimates of conditions that would occur in 1987 with 3) no controls (1987 no controls comparison), 4) with prevailing practice

controls (1987 prevailing practice comparison), and 5) with 1982 levels of controls (called the 1987 82 control comparison or 1987 curtailed control comparison). The comparisons are made as if Federal Standards do not exist.

The four air basin "best" economic measure of total annual quantified air pollution control benefits are estimated as approximately: $9.8 billion in the 1979 no control comparison, $7.8 billion in the 1979 prevailing practice comparison, $11.9 billion in the 1987 no control comparison, $9.0 billion in the 1987 prevailing practice comparison, and $1.0 billion in the 1987 curtailed controls comparison (all in 1982 dollars). Consideration of omitted pollutants and regions, and of physical impacts and economic values that could not be quantified, suggests the analysis may be capturing only 50 percent of total economic values. There is also considerable uncertainty in the estimates, as reflected by upper bound estimates roughly double the best estimates and lower bound estimates on the order of 10 percent of the best estimates. This large range is primarily due to uncertainties in the ability to confidently measure and value mortality impacts.

The approximate breakdown of the best benefit estimates by effects category is: 67 percent human health (54% mortality/13% morbidity), 29 percent materials damage and soiling, 4 percent visibility, and less than 1 percent vegetation (agriculture and forests). Very few of the potential forest benefits were felt to be captured. The breakdown by air basin is: 25 percent in the South Coast, 46 percent in the San Francisco Bay Area, 15 percent in San Diego, and 14 percent in the San Joaquin Valley. The percentages of the upper bound estimates for the South Coast and the San Francisco Air Basin are reversed. The breakdown of benefits by pollutants is more difficult as their effects are difficult to separate. Nevertheless, the pollutants with the largest change in ambient concentrations and those most likely related to the largest control benefits are total suspended particulates and sulfur compounds. The smallest benefits were associated with changes in ozone. This was due to small predicted changes in ozone across the scenarios. The value of changes in lead concentrations could not be economically quantified.

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Regardless of the involvement of the above-mentioned individuals, the responsibility for errors and omissions remain with the project manager.

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RDR
Boulder, Co.
June, 1985

DISCLAIMER

The statements and conclusions in this report are those of the contractor and not necessarily those of the California Air Resources Board. The mention of commercial products, their sources or their use in connection with material reported herein is not to be construed as either an actual or implied endorsement of such products.

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1.0 INTRODUCTION

1.1 OBJECTIVE

For more than a decade, the U.S. Environmental Protection Agency (EPA), the California Air Resources Board (CARB) and local air pollution control districts have pursued strategies aimed at achieving and maintaining Federal and state air quality standards in California. Evaluating the effects of past efforts and maximizing the net benefits of current efforts to improve air quality is a major concern to government, industry, and the public. However, such examination is limited by a lack of detailed information on the benefits (or damages) of controlling (or not controlling) air pollution.

The objective of this research was, to the degree possible, to provide quantitative estimates of economic measures of benefits (or damages) from controlling air pollution under alternative air pollution control scenarios. While it is important to recognize and discuss the conceptual and practical limitations in conducting such an analysis, the overriding focus of this effort was to use the best available literature, data, methods and professional judgement to estimate and represent as fully and accurately as possible the economic measures of air pollution control benefits.

To meet the objective, the study used alternative pollution control scenarios that allow 1979 actual and 1987 planned emissions controls to be compared to more lenient potential alternative control levels. The first stage in the analysis was to estimate what emissions and ambient concentrations of pollution would be under each alternative scenario. Next, based upon changes in ambient concentrations in pollutants across the scenarios, changes in physical and economic measures of air pollution benefits were estimated. A broad range of pollutants and effects categories were included in the analysis and, to represent the uncertainty in the estimates, "best", "upper bound" and "lower bound" economic estimates are provided for those effects categories that have been quantified.

1.2 STUDY DESIGN

The linkages between changes in regulatory policies (or alternative scenarios of air pollution control) to economic valuation of impacts are illustrated in Figure 1.1. The study was designed to meet the stated objectives by following this flow chart. Initially, seven alternative air pollution control scenarios were defined, including actual conditions in 1979 as the "baseline". Under each alternative scenario, emissions and ambient concentrations were estimated for selected pollutants and for visibility at selected locations. The emissions and ambient air quality analysis was performed by Systems Applications Inc. These estimates consider prevailing engineering practice, air pollution regulatory compliance strategies, and atmospheric and topographic conditions under each alternative scenario.

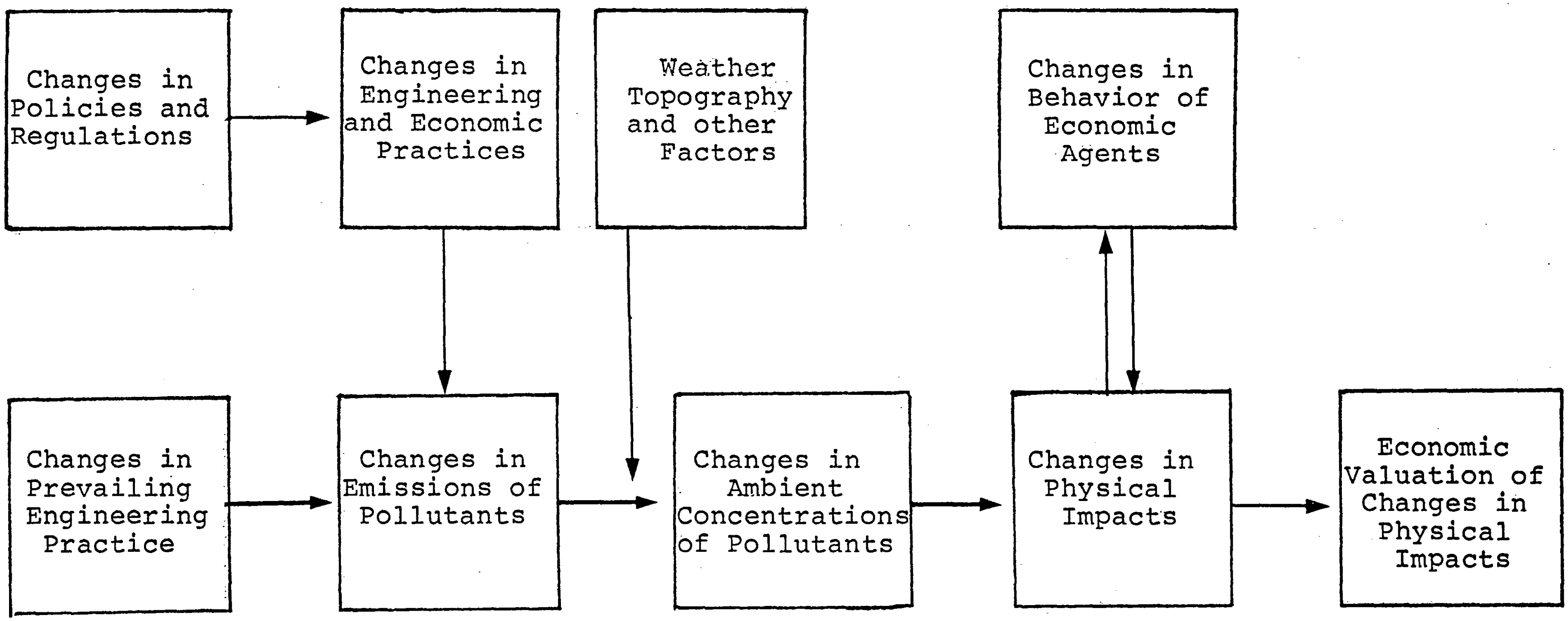
The physical impacts, and economic valuation of impacts, to society's health and well-being from changes in air pollution conditions were estimated by Energy and Resource Consultants, Inc. using the ambient air quality data provided by Systems Applications, Inc. The analysis used results of previously conducted studies on the physical impacts of air pollution and their economic valuation. The analysis considered both physical damage and mitigating behavior that economic agents undertake to reduce air pollution impacts. Economic agents often respond to changes in air pollution conditions with efforts to mitigate (or respond to) potentially adverse impacts. For example, the formulation of many materials has been altered so that the material is more resistant to air pollutants. The estimated changes in economic damages to materials from a change in air pollution account for, to the degree possible, the change in physical effects that occur as well as the change in activities to mitigate adverse effects.

STUDY AREAS

Four California air basins were included in the analysis: the San Diego Air Basin (SDAB), the South Coast Air Basin (SCAB), the San Joaquin Valley Air Basin (SJVAB) and the San Francisco Bay Area Air Basin (SFBAB). The locations

Figure 1-1

Schematic of the Relationship Between
Changes in Air Pollution Control Regulations
and Economic Measures of Benefits



and areas covered by these air basins are shown in Figures 1-2 through 1-6. These air basins were selected due to their combined importance in terms of population and known air pollution problems. The combined populations of these four air basins include approximately 80 percent of California's total population (See Table 1-1). Air pollution damage in these four areas probably represents well over 80% of total damages statewide as there is generally much less air pollution in other California air basins. The four air basins were broken down into 641 "supertracts" for analysis purposes. Each supertract is a collection of 3-15 adjacent census tracts. The average population of a supertract is just over 30,000 people. All ambient air quality, physical effects and economic analyses and calculations were carried out at the supertract level of detail and then aggregated to air basin totals.

POLLUTANTS

Six emitted and six ambient pollutants were considered in the analysis:

EMITTED	AMBIENT
Particulate matter (PM)	Total Suspended Particulates (TSP)
Nitrogen oxides (NO_x)	Nitrogen Dioxide (NO_2)
Sulfur oxides (SO_x)	Sulfur Dioxide (SO_2)
Carbon monoxide (CO)	Sulfates (SO_4)
Lead (PB)	Lead (PB)
Reactive organic gases (ROG)	Ozone (O_3)

The ambient pollutants selected were those that account for a substantial portion of known air pollutant effects upon humans and the ecosystem and for which defensible quantitative information were available to estimate emissions, ambient concentrations, and physical and economic measures of impacts. The emitted pollutants were selected as those that result in the ambient pollutants of interest.

Figure 1-2
California Air Basins

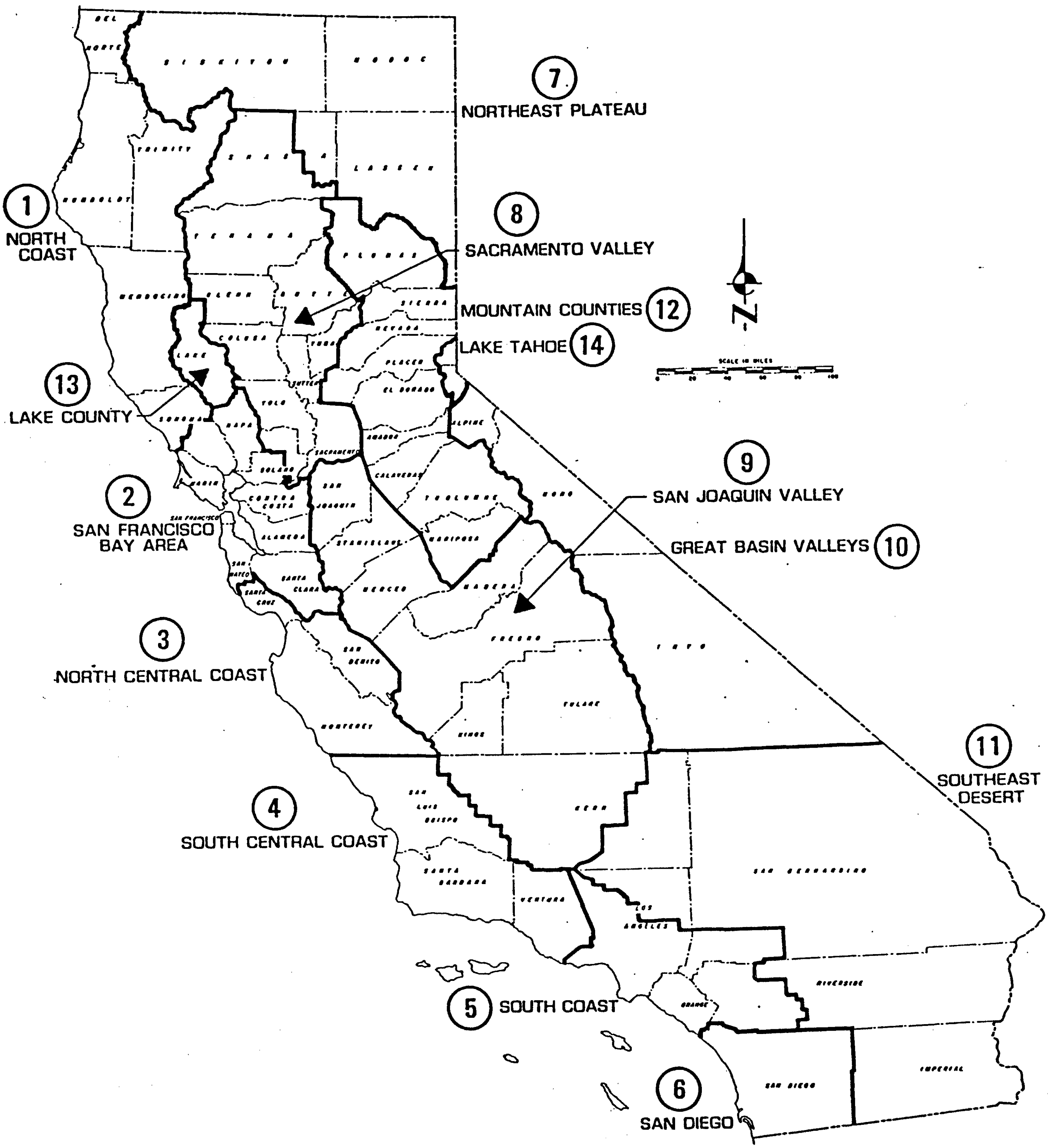
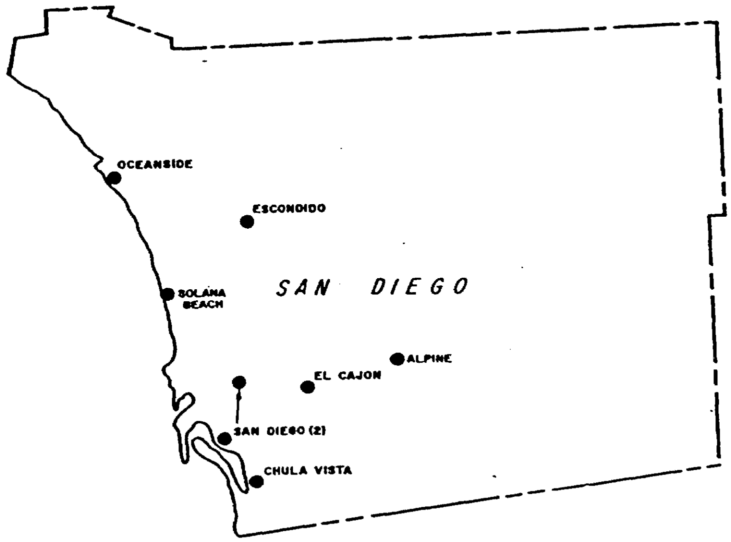
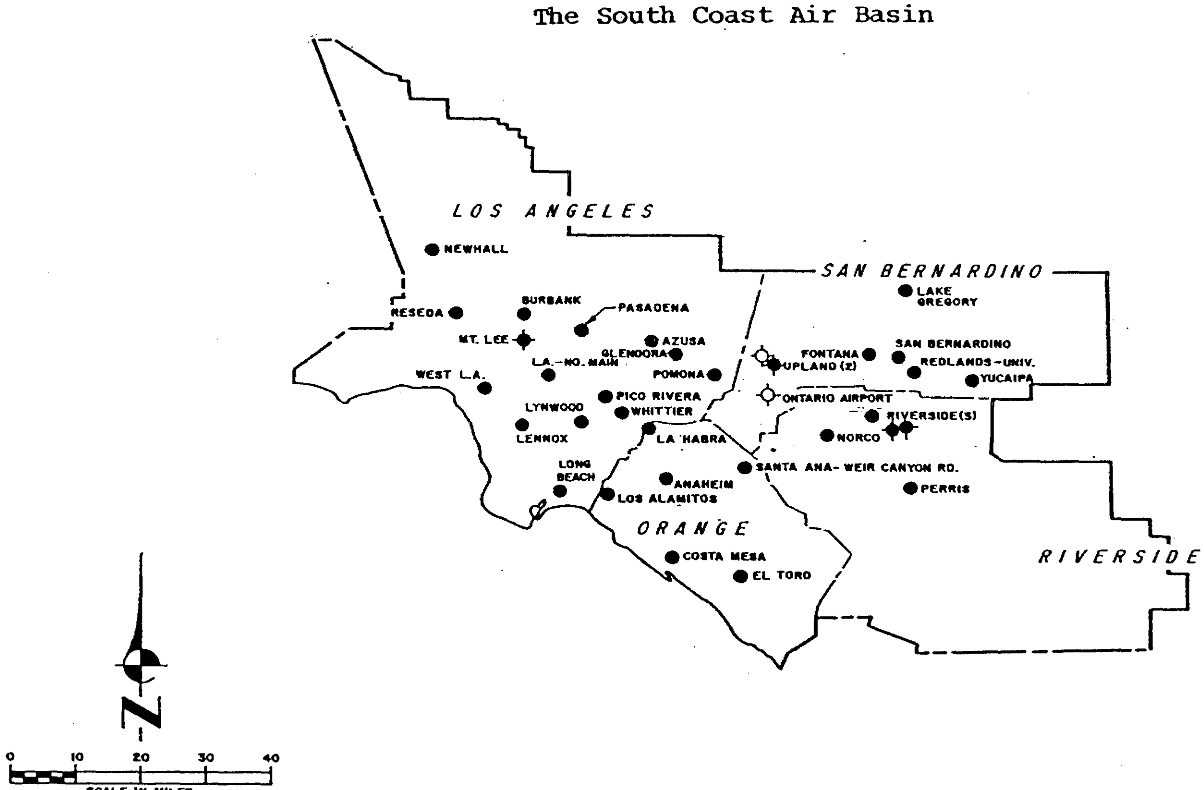


Figure 1-3
The San Diego Air Basin



● – Gaseous pollutant or multipollutant monitoring site
○ – High volume particulate sampling only
⌖ – ARB operated site

Figure 1-4
The South Coast Air Basin



● – Gaseous pollutant or multipollutant monitoring site
○ – High volume particulate sampling only
⌖ – ARB operated site

OPERATING STATIONS, DEC. 1980

Figure 1-5
The San Joaquin Valley Air Basin

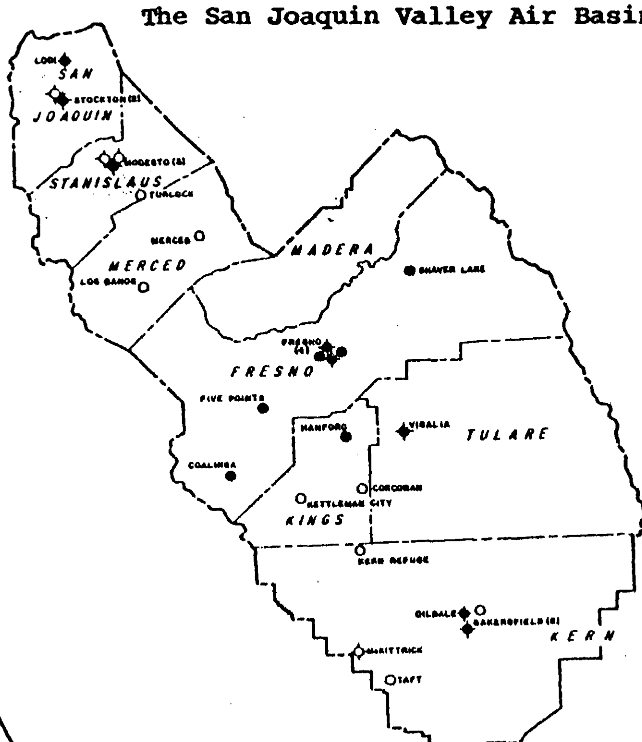


Figure 1-6
The San Francisco Bay Area Air Basin

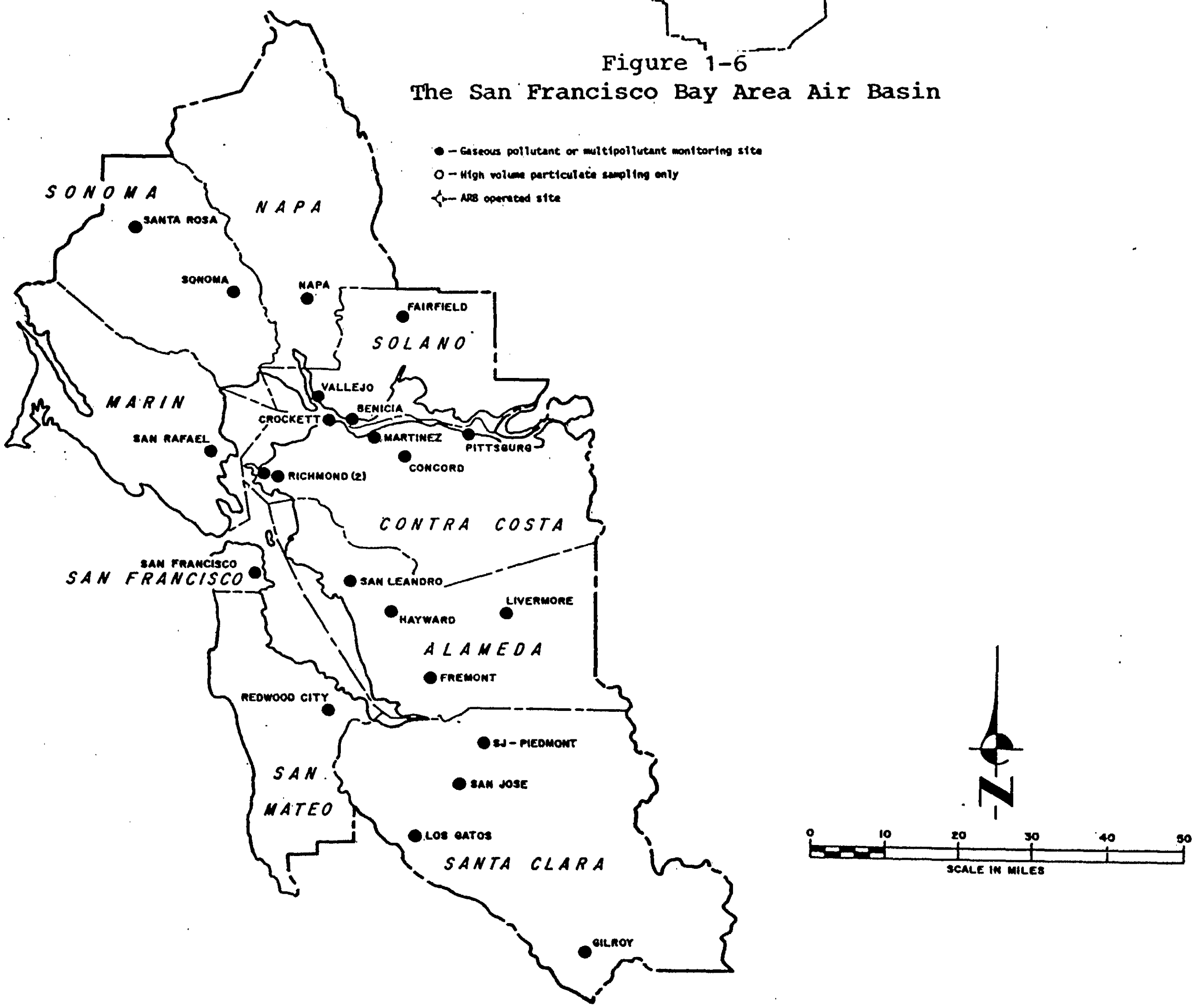


Table 1-1

POPULATION IN THE STUDY AIR BASINS IN 1980

AREA	POPULATION	PERCENT OF STUDY AREAS	PERCENT OF STATE
San Diego Air Basin	1,861,814	9.76%	7.87%
South Coast Air Basin	10,217,514	53.56%	43.17%
San Joaquin Valley Air Basin	2,045,029	10.72%	8.64%
San Francisco Bay Area Air Basin	4,952,471	25.96%	20.92%
Study Area Total	19,076,828	100.00%	80.60%
California	23,667,900	--	100.00%

Populations calculated by matching census tracts to air basin boundary definitions. All data from the 1980 U.S. Census.

EFFECTS CATEGORIES

Economic measures of damages were estimated for the following effects categories:

- o HUMAN HEALTH including changes in the risks of mortality and morbidity.
- o AGRICULTURE including commercial crops.
- o MATERIALS including materials deterioration, damage and soiling.
- o FORESTS including impacts to tree productivity that result in reduced commercial yields and reduced recreation aesthetics.
- o VISIBILITY AESTHETICS including visibility impairment in residential and recreational areas.

For many effects categories, both physical and economic measures of changes in effects due to changes in air pollution control scenarios are quantified. In other categories, most studies combine physical and economic estimates into one damage function. For example, instead of estimating the amount of paint lost due to air pollution in a study region, studies will typically estimate a damage rate and combine the physical and economic damages into one function, which has then been used in this report. Therefore, while changes in economic measures of damages for each effects category are always presented, changes in physical effects are not necessarily presented.

In each damage category, effects were quantified whenever defensible damage functions could be identified. Nevertheless, numerous effects within a category are suspected of being caused by air pollutants at levels expected in one or more of the alternative scenarios, but no defensible damage functions could be identified for use in this analysis. Consequently, due to omissions in damages in each category, the "best" economic estimates of benefits, even given inaccuracy in the estimates, are likely to understate total benefits of air pollution controls for the category.

AIR POLLUTION CONTROL SCENARIOS

Seven air pollution control scenarios and five comparisons were examined, as summarized in Table 1-2. Scenarios 1 and 7 represent two points of comparison: the actual emissions in 1979 and the emissions predicted to occur with the controls planned in 1987. The 1987 planned controls are based upon published state and local air pollution control implementation plans. The "1960" scenarios (2 and 4) represent hypothetical scenarios with no federal, state or local regulations of source emissions beyond levels in use in 1960. The "prevailing practice" scenarios (3 and 5) represent conditions where the only air pollution controls would be those controls that, in the absense of any emissions control regulations, would have been implemented voluntarily for reasons other than air pollution control, but would have decreased emissions. The "1982 controls" scenario (6) represents what would occur in 1987 if regulations that were in effect in 1982 remained in force in 1987, but no additional regulations were implemented. The confounding effects of the existence of federal air pollution control standards are not considered.

The scenario comparisons represent the economic benefits to human health and welfare from:

- o Having emissions at actual 1979 levels rather than at higher levels in 1979 (Comparisons 1 and 2), and
- o Having emissions that would occur with 1987 planned controls rather than higher emissions levels in 1987 (Comparisons 3,4 and 5).

1.3 COMPARISONS WITH PREVIOUS STUDIES

Several previous attempts have been made to estimate economic measures of air pollution damage both in California (Fisher et al. 1979, Hamilton 1979, Westman and Conn 1976) and nationwide (Freeman 1982, Waddell 1974, and Crocker 1979). This effort has made significant improvements over previous attempts, yet is still subject to many of the same limitations.

Table 1-2

STUDY SCENARIOS AND SCENARIO COMPARISONS

STUDY SCENARIOS

1. Actual 1979 emissions (base year)
2. Estimated 1979 emissions with 1960 air pollution controls (1979 No Control--Worst Case)
3. Estimated 1979 emissions with prevailing engineering practice controls (1979 No Control--Prevailing Practices).
4. Predicted 1987 emissions with 1960 air pollution controls (1987 No Control--Worst Case).
5. Predicted 1987 emissions with prevailing engineering practice controls (1987 No Control--Prevailing Practice).
6. Predicted 1987 emissions with curtailed (1982) controls (1987 Curtailed Controls).
7. Predicted 1987 emissions with planned controls (1987 Planned Controls).

SCENARIO COMPARISONS

COMPARISON #1. 1979 NO CONTROL
1979 without controls versus actual controls (Scenario 1 versus Scenario 2)

COMPARISON #2. 1979 PP CONTROL
1979 with prevailing engineering practice controls only versus actual controls (Scenario 1 versus Scenario 3)

COMPARISON #3. 1987 NO CONTROL
1987 without controls versus planned controls (Scenario 7 versus Scenario 4)

COMPARISON #4. 1987 PP CONTROL
1987 with prevailing engineering practice controls only versus planned controls (Scenario 7 versus Scenario 5)

COMPARISON #5. 1987 82 CONTROL
1987 with 1982 level of controls versus planned controls (Scenario 7 versus Scenario 6)

Improvements Over Previous Efforts

Relative to previous efforts this study represents significant advances in the following areas:

- Policy based scenarios are used providing results more useful for policy analysis.

- More pollutants are considered than has heretofore been the case. As a result, more effects categories are able to be analyzed and included.

- Estimation of changes in emissions, visibility, and ambient concentrations for each pollutant allow more precise estimation of the benefits of air pollution control. Many past studies have estimated air pollution control benefits for a given percentage change in one or more pollutants, which is assumed to be the same for all pollutants, scenarios and locations. However, the rate of change in ambient concentrations of different pollutants is seldom similiar across different pollutants, scenarios and locations. In fact, this study finds significantly different rates of change in ambient concentrations for different pollutants across the different scenarios. As a result, some of the economic estimates at first appear quite suprising.

- The scenarios consider planned controls in 1987, rather than meeting state and federal standards. Because planned emissions controls are generally not predicted to result in meeting ambient air quality standards, the physical and economic estimates of benefits are often less than have been predicted in previous benefits studies of air pollution control (For example, see Rowe and Chestnut 1985).

- Different concentration measures are estimated for each pollutant, as required in the physical and economic damage estimation procedures. This is important because a percentage change in one air pollution measure, such as the annual average, will not equal the same percentage change in another measure, such as the number of hours exceeding a certain threshold. Ignoring these differences may have biased previous studies.

- The ambient air pollution measures have been disaggregated to a level that represents more accurately human and ecosystem exposures than has been accomplished in previous multi-pollutant studies. For example, for many pollutants, a county average concentration would greatly misstate the average exposure of the population, crops and forests if there are any unusual population distribution patterns.

- More damage categories have been included and analyzed in detail than in any past multi-pollutant study. More subcategories of damages have also been included. This reflects our ability to utilize and benefit from an ever growing literature on the physical and economic damages of air pollution.

Limitations Consistent With Past Studies

This study suffers many of the same limitations as previous efforts but, due to research progress, to a lesser degree. The most significant limitations are omissions and inaccuracy.

The omissions include pollutants, effects categories and locations. The study was only able to attempt to quantify damages from a handful of pollutants. Potentially significant damages from acid rain, carbon monoxide, air borne toxic substances and carbon dioxide represent but a few of the pollutants that were not included. Many possible effects categories and subcategories have also been omitted due to lack of adaquate quantative information or due to previous evidence that these effects are small compared to the many effects that were included. Among these are ecosystem effects on the protection of habitat, flora, and fauna; soil erosion and reduced water conservation associated with forest degradation; recreational and commercial fishery losses; global climate effects; and many suspected health effects. Other effects not included were interbasin transfers of pollution effects on other California air basins not considered in this report.

Inaccuracy pervades the analysis. Estimates of emissions, ambient concentrations, and physical and economic measures of damages under each alternative scenario are all subject to inaccuracy. The inaccuracy from one step is further compounded by the use of the data in the next step. Limited and contradictory evidence compounds the difficulty in estimating physical and economic measures of damage. The approach in this study has not been to resolve such controversies, but to select those studies that seem to represent the "best", "upper" and "lower" estimates of air pollution control benefits that have some professional credibility. These studies were selected in terms of their theoretical validity, applicability and presumed accuracy and professional acceptance.

1.4 ORGANIZATION OF THE REPORT

This report is organized in two volumes. The first volume includes Chapters 1 and 2, which provide a summary of the objectives, methods (Chapter 1) and results (Chapter 2). Volume I serves as an extended executive summary of the study. Volume II covers the detailed study procedures and findings (Chapters 3 through 9). Chapters 3-9 include the following materials:

- Chapter 3. Methods and results for the estimation of emissions and ambient pollutant concentrations, and visibility conditions under the alternative scenarios.
- Chapter 4. A summary of concepts and methods used to estimate economic measures of benefits from air pollution control.
- Chapter 5. Methods and results for the estimation of human health benefits.
- Chapter 6. Methods and results for the estimation of agricultural benefits.
- Chapter 7. Methods and results for the estimation of materials damage.
- Chapter 8. Methods and results for the estimation of forest benefits.

- o Chapter 9. Methods and results for the estimation of visibility aesthetic benefits.

Each of Chapters 5-9 follow a parallel organizational theme. The types of benefits from air pollution control are identified, followed by selection of physical damage functions for each of the study pollutants. Economic damage functions for categories of physical damages are selected. Next, a brief subjective assessment is presented concerning the relative importance of benefits that have been included versus potential benefits that have been omitted in the analysis and the accuracy of the analysis. Finally results of the assessment are presented for each air basin and scenario comparison.

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2.0 SUMMARY OF RESULTS

2.1 EMISSIONS AND AMBIENT CONCENTRATIONS

2.1.1 Emissions

This section summarizes the 32 emission inventories that were developed during this study. The inventories covered 8 scenarios in 4 California Air Basins (22 counties) for 6 pollutants. In general, these inventories were developed from a 1979 base year emission inventory through the use of growth and control factors, by scenario, for each individual air basin. The 1979 emissions data base used throughout the inventory task was obtained from the ARB Emission Data System. Emissions were identified in the data base by facility and devise (process) for point sources, and area source emissions were provided by category. During the study, emission estimates were developed by county (or county portions) for each of the 4 air basins in the study. Emissions were estimated in tons per year (TPY) for the six pollutants identified on page 1-4.

2.1.1.1 Inventory Scenarios

The eight scenarios represented alternative levels of emission control for three time periods 1960, 1979, and 1987. These scenarios include a 1960 baseline plus the seven scenarios identified in Table 1-2.

The 1979 base year inventory was used to generate inventories for each of the other scenarios.

The 1960 inventory was developed by estimating the changes in the levels of growth and control between 1979 and 1960 for point and area sources. Using the ARB system for projecting inventories, factors were estimated for the 63 growth and the 101 control codes used in this study. Since different emission control technology is used for different pollutants, the control factors were developed for each of the 6 pollutants in the study.

The 1979 no control worst case scenario represented the hypothetical case of no federal, state, or local regulation of source emissions beyond the control levels in use in 1960. The 1970 no control worst case inventory was developed by applying the 1960 control factors for each control code to the 1979 base year inventory for the four air basins. Similar in concept to the 1979 no control worst case scenario, the 1987 no control worst case inventory represented the hypothetical case of no regulation of emissions beyond the control levels in use in 1960. Growth factors were derived from ARB growth profiles to account for the levels of source activity estimated to occur in 1987.

In contrast to the no control worst case scenario, emission estimates were also developed for a 1979 no control prevailing practices scenario. Prevailing practices were defined as actions that, in the absence of any emission control regulations, would have been implemented voluntarily by industry for reasons of product improvement, public relations, economics, or safety, and that would have resulted in a decrease in emissions.

Similarly, the inventory for the 1987 no control prevailing practices scenario was developed for each air basin by applying the prevailing practices control factors, and the 1987 ARB growth factors, to the 1979 base year inventory.

The 1987 curtailed controls scenario represented the hypothetical case of partial regulation of source emissions. The definition of the 1987 curtailed controls scenario was that all control regulations in full effect as of 1 July 1982 remained in force in 1987, but that all subsequent regulations, including those already adopted but not yet in full force, were not implemented. In general, this scenario represented a 1987 inventory with 1982 emission controls.

The 1987 planned controls scenario assumed that existing control regulations remained in force in 1987 and that all regulations planned by the ARB and by local control districts for implementation by 1987 took effect.

2.1.1.2 Emission Inventory Results

Tables 2-1 through 2-4 present the change in emissions from the 1960 baseline inventory by scenario and air basin. As shown in these tables, there is a wide range of emissions over the eight scenarios for every pollutant and air basin. As expected, emissions are generally at the highest level for the 1987 no control worst case scenario. In contrast emissions of ROG, CO, NO_x, and PB are at the lowest level, for the most part, in the 1987 planned controls scenario; SO_x emissions are lowest in the 1987 planned controls or 1979 base year scenario depending on the air basin; and PM emissions are generally lowest in the 1979 base year scenario. In conclusion, these inventories demonstrate that federal, state, and local control agencies have had, and will continue to have, a significant beneficial effect on emission levels in the state. On the basis of these inventories, much has been accomplished in reducing emissions from a variety of source categories in California.

2.1.2 Ambient Concentrations and Visibility

The various damage functions (health, agricultural, crop, etc.) require ambient concentrations of lead, total suspended particulate matter (TSP), sulfur dioxide, sulfate, nitrogen dioxide and ozone as inputs in order to calculate the actual damage for the various emission scenarios described in the previous section. In order to estimate pollutant concentrations for the various emission scenarios, ambient air quality measurements of the six pollutants at monitoring stations in the four air basins were obtained from California Air Resources Board (CARB) for a three year period from 1978 to 1980. Statistical annual averages, frequency distributions, and cumulative frequency distributions were calculated for each pollutant at each station. From the CARB set of air monitoring stations, a subset was chosen to represent geographic and/or population areas based on census tract information which was combined into larger tracts called supertracts. This subset was developed based on the location of the station and its proximity to the centroid of the supertracts.

Table 2-1

Change in Emissions from the 1960
Baseline Inventory for the San Diego Air Basin

Scenario	Change in Emissions (percent)					
	ROG	CO	NO_x	SO_x	PM	PB
1979 Base Year	+14	+27	+98	+4	+14	+10
1979 No Control--Worst Case	+138	+164	+152	+195	+59	+172
1979 No Control--Prevailing Practices	+107	+90	+152	+142	+47	+172
1987 No Control--Worst Case	+207	+247	+253	+321	+102	+259
1987 No Control--Prevailing Practices	+167	+148	+253	+245	+87	+259
1987 Curtailed Controls	+14	+36	+140	+47	+45	-16
1987 Planned Controls	-13	-1	+89	+45	+44	-63

Table 2-2

Change in Emissions from the 1960
Baseline Inventory for the San Francisco Air Basin

Scenario	Change in Emissions (percent)					
	ROG	CO	NO_x	SO_x	PM	PB
1979 Base Year	-10	+2	+37	-9	-14	-12
1979 No Control--Worst Case	+82	+114	+69	+54	+39	+119
1979 No Control--Prevailing Practices	+58	+53	+69	+38	+24	+119
1987 No Control--Worst Case	+116	+164	+103	+73	+57	+173
1987 No Control--Prevailing Practices	+87	+89	+103	+54	+41	+173
1987 Curtailed Controls	-20	+4	+48	+1	-1	-36
1987 Planned Controls	-39	-23	+23	0	-2	-72

Table 2-3

Change in Emissions from the 1960 Baseline
Inventory for the San Joaquin Valley Air Basin

Scenario	Change in Emissions (percent)					
	ROG	CO	NO_x	SO_x	PM	PB
1979 Base Year	+15	+10	+55	+24	+23	-12
1979 No Control--Worst Case	+65	+97	+66	+33	+49	+117
1979 No Control--Prevailing Practices	+53	+50	+66	+33	+42	+117
1987 No Control--Worst Case	+135	+138	+130	+140	+64	+165
1987 No Control--Prevailing Practices	+121	+80	+130	+139	+56	+165
1987 Curtailed Controls	-17	+14	+96	+70	+35	-37
1987 Planned Controls	-25	-9	+70	-19	+35	-73

Table 2-4

Change in Emissions from the 1960
Baseline Inventory for the South Coast Air Basin

Scenario	Change in Emissions (percent)					
	ROG	CO	NO_x	SO_x	PM	PB
1979 Base Year	-2	+4	+51	-36	+47	-9
1979 No Control--Worst Case	+98	+114	+81	+100	+66	+118
1979 No Control--Prevailing Practices	+73	+54	+81	+69	+61	+118
1987 No Control--Worst Case	+134	+158	+96	+31	+73	+165
1987 No Control--Prevailing Practices	+103	+85	+96	+15	+68	+165
1987 Curtailed Controls	-12	+2	+49	-46	+53	-35
1987 Planned Controls	-42	-24	0	-69	+47	-69

The statistical calculations are associated with the 1979 baseline emission scenario. Summaries of pollutant concentrations are shown in Table 2-5. Pollutant concentration estimates for the various emission scenarios were made based on percentage emission changes from the 1979 baseline emission scenario for the nonreactive pollutants (lead, TSP, sulfur dioxide and sulfate) and nitrogen dioxide. Although nitrogen dioxide (NO_2) is involved in photochemical smog formation, usually peak NO_2 is equal to the total nitrogen oxides (NO_x). Thus, we can assume that peak NO_2 varies linearly with NO_x emissions. Since ozone is a major product of photochemical mechanisms due to hydrocarbon (ROG) and NO_x emissions, ozone estimates were made with the Empirical Kinetics Modeling Approach (EKMA) as outlined by EPA (1981) and EPA (1984).

Resultant pollutant concentration estimates for the nonreactive species and NO_2 vary according to the emission changes as described in the previous section. Frequency distributions for each pollutant were shifted based on emission changes. Ozone concentrations for the different emission scenarios vary less than the hydrocarbon and NO_x emission changes. The ozone changes are similar to previous EKMA studies of Los Angeles, San Francisco, and Sacramento (Whitten and Hogo, 1981; and Whitten, Hogo, and Johnson, 1981). Since EKMA gives changes in peak 1-hour ozone, we do not expect the same magnitude of change to apply to lower ozone concentrations. Therefore, we linearly decrease the percentage change from the maximum ozone modeled to zero at a background ozone value. Background ozone at 0.02 ppm was chosen for the four air basins. Because of the methodology used to estimate ozone, longer term statistical averages (annual, 6 month) which are usually near background showed little to no change for the different emission scenarios. The ozone estimates may be subject to some unquantifiable inaccuracy, yet this inaccuracy would have minimal inpact on the total economic estimates reported (see Chapter 3).

Summary of the estimated concentrations for the different pollutants are shown in Table 2-6 through Table 2-11.

Estimates of visibility impairment due to the different emission scenarios can be made using the TSP, sulfate, and nitrate concentrations based on regression

Table 2-5

Annual Mean Pollutant Concentrations for Selected Stations

in the Four Air Basins from 1978 to 1980

Station Name	Lead (ug/m3)	TSP (ug/m3)	SO2 (pphm)	SO4 (ug/m3)	NO2 (pphm)	Ozone (pphm)
(a) San Diego Air Basin						
EL CAJON	1.08	86.23	0.53	6.84	4.17	2.26
SAN DIEGO-ISLAND	0.89	86.20	0.46	8.20	3.89	2.60
(b) San Francisco Air Basin						
PITTSBURG	0.35	71.99	0.28	5.36	2.07	2.04
RICHMOND-13 ST	0.46	57.17	0.14	7.46	2.23	1.66
SAN JOSE	0.78	77.02	5.00	3.96	3.67	1.63
SAN FRANCISCO	0.89	49.80	0.23	5.99	3.18	1.00
(c) San Joaquin Air Basin						
FRESNO-OLIVE	1.40	131.82	0.31	5.30	3.26	2.16
BAKERSFIELD-CHESTER	1.31	163.02	1.04	10.66	4.01	2.38
(d) South Coast Air Basin						
COSTA MESA-PLACENTIA	0.63	98.38	0.48	9.93	2.60	1.91
SAN BERNARDINO	--	--	1.01	11.66	--	3.94
AZUSA	0.97	120.53	0.71	10.21	4.21	4.23
LOS ANGELES-MAIN	1.66	123.44	1.10	11.93	6.22	2.29

Table 2-6

Estimated Lead Concentrations µg/ m3) for Selected Stations

for the Different Emission Scenarios

Station Name	1979 no control worst case	1987 no control worst case	1979 prevail practice	1987 prevail practice	1987 curtail control	1987 planned control
(a) San Diego Air Basin						
EL CAJON	2.68	3.54	2.68	3.54	0.83	0.36
SAN DIEGO-ISLAND	2.21	2.92	2.21	2.92	0.68	0.30
(b) San Francisco Air Basin						
PITTSBURG	0.87	1.08	0.87	1.08	0.25	0.11
RICHMOND-13 ST	1.14	1.42	1.14	1.42	0.33	0.14
SAN JOSE	1.94	2.41	1.94	2.41	0.56	0.25
SAN FRANCISCO	2.21	2.74	2.21	2.74	0.64	0.28
(c) San Joaquin Air Basin						
FRESNO-OLIVE	3.46	4.25	3.46	4.25	1.00	0.44
BAKERSFIELD-CHESTER	3.24	3.97	3.24	3.97	0.94	0.41
(d) South Coast Air Basin						
COSTA MESA-PLACENTIA	1.52	1.87	1.52	1.84	0.45	0.21
AZUSA	2.34	2.87	2.34	2.84	0.70	0.33
LOS ANGELES-MAIN	4.00	4.92	4.00	4.86	1.19	0.56

Table 2-7

Estimated Total Suspended Particulates (μg/m3) for Selected Stations

for the Different Emission Scenarios

Station Name	1979 no control worst case	1987 no control worst case	1979 prevail practice	1987 prevail practice	1987 curtail control	1987 planned control
(a) San Diego Air Basin						
EL CAJON	120.76	153.02	111.53	141.73	109.73	109.20
SAN DIEGO-ISLAND	120.72	152.97	111.49	141.68	109.69	109.16
(b) San Francisco Air Basin						
PITTSBURG	116.67	131.91	103.83	118.11	83.03	82.60
RICHMOND-13 ST	92.65	104.75	82.46	93.79	65.93	65.60
SAN JOSE	124.83	141.12	111.09	126.36	88.83	88.37
SAN FRANCISCO	80.71	91.25	71.83	81.70	57.43	57.14
(c) San Joaquin Air Basin						
FRESNO-OLIVE	158.91	174.91	151.33	166.36	144.17	144.08
BAKERSFIELD-CHESTER	196.52	216.31	187.15	205.73	178.30	178.18
(d) South Coast Air Basin						
COSTA MESA-PLACENTIA	110.68	115.54	107.32	112.31	101.98	98.04
AZUSA	135.60	141.55	131.49	137.60	124.94	120.11
LOS ANGELES-MAIN	138.87	144.97	134.66	140.92	127.96	123.01

Table 2-8

Estimated SO2 Concentrations (pphm) for Selected Stations

for the Different Emission Scenarios

Station Name	1979 no control worst case	1987 no control worst case	1979 prevail practice	1987 prevail practice	1987 curtail control	1987 planned control
		(a) San Diego Air Basin				
EL CAJON	1.51	2.15	1.24	1.76	0.75	0.74
SAN DIEGO-ISLAND	1.31	1.87	1.07	1.53	0.65	0.64
		(b) San Francisco Air Basin				
PITTSBURG	0.47	0.53	0.42	0.48	0.31	0.31
RICHMOND-13 ST	0.24	0.27	0.21	0.24	0.16	0.15
SAN JOSE	8.47	9.52	7.56	8.48	5.52	5.49
SAN FRANCISCO	0.39	0.44	0.35	0.39	0.25	0.25
		(c) San Joaquin Air Basin				
FRESNO-OLIVE	0.33	0.60	0.33	0.60	0.43	0.20
BAKERSFIELD-CHESTER	1.12	2.01	1.11	2.01	1.43	0.68
		(d) South Coast Air Basin				
COSTA MESA-PLACENTIA	1.49	0.98	1.26	0.86	0.40	0.23
SAN BERNARDINO	3.14	2.07	2.66	1.81	0.85	0.49
AZUSA	2.20	1.45	1.87	1.27	0.59	0.35
LOS ANGELES-MAIN	3.41	2.25	2.89	1.97	0.92	0.53

Table 2-9

Estimated SO4 Concentrations (μg/m3) for Selected Stations

for the Different Emission Scenarios

Station Name	1979 no control worst case	1987 no control worst case	1979 prevail practice	1987 prevail practice	1987 curtail control	1987 planned control
(a) San Diego Air Basin						
EL CAJON	19.47	27.76	15.97	22.77	9.68	9.55
SAN DIEGO-ISLAND	23.34	33.28	19.14	27.30	11.61	11.44
(b) San Francisco Air Basin						
PITTSBURG	9.08	10.21	8.10	9.09	5.92	5.89
RICHMOND-13 ST	12.63	14.21	11.28	12.65	8.24	8.19
SAN FRANCISCO	10.14	11.41	9.06	10.16	6.62	6.58
(c) San Joaquin Air Basin						
FRESNO-OLIVE	5.69	10.24	5.67	10.22	7.28	3.47
BAKERSFIELD-CHESTER	11.44	20.59	11.41	20.56	14.65	6.98
(d) South Coast Air Basin						
COSTA MESA-PLACENTIA	30.82	20.30	26.13	17.82	8.31	4.82
SAN BERNARDINO	36.19	23.84	30.68	20.92	9.76	5.66
AZUSA	31.69	20.88	26.87	18.32	8.55	4.96
LOS ANGELES-MAIN	37.03	24.39	31.39	21.41	9.99	5.79

Table 2-10

Estimated NO2 Concentrations (pphm) for Selected Stations

for the Different Emission Scenarios

Station Name	1979 no control worst case	1987 no control worst case	1979 prevail practice	1987 prevail practice	1987 curtail control	1987 planned control
(a) San Diego Air Basin						
EL CAJON	5.31	7.43	5.31	7.43	5.05	3.98
SAN DIEGO-ISLAND	4.95	6.93	4.96	6.93	4.71	3.72
(b) San Francisco Air Basin						
PITTSBURG	2.57	3.07	2.57	3.07	2.24	1.87
RICHMOND-13 ST	2.76	3.31	2.76	3.31	2.41	2.01
SAN JOSE	4.55	5.45	4.55	5.45	3.97	3.31
SAN FRANCISCO	3.94	4.72	3.94	4.72	3.44	2.87
(c) San Joaquin Air Basin						
FRESNO-OLIVE	3.49	4.84	3.49	4.84	4.11	3.57
BAKERSFIELD-CHESTER	4.29	5.95	4.29	5.95	5.06	4.40
(d) South Coast Air Basin						
COSTA MESA-PLACENTIA	3.12	3.37	3.12	3.37	2.57	1.73
AZUSA	5.05	5.46	5.05	5.46	4.16	2.80
LOS ANGELES-MAIN	7.46	8.07	7.46	8.07	6.14	4.13

Table 2-11

Estimated Ozone Concentrations (pphm) for Selected Stations

for the Different Emission Scenarios

Station Name	1979 no control worst case	1987 no control worst case	1979 prevail practice	1987 prevail practice	1987 curtail control	1987 planned control
(a) Annual Average						
San Diego Air Basin						
EL CAJON	2.27	2.28	2.27	2.28	2.26	2.26
SAN DIEGO-ISLAND	2.62	2.64	2.62	2.64	2.60	2.59
San Francisco Air Basin						
PITTSBURG	2.04	2.04	2.04	2.04	2.04	2.04
RICHMOND-13 ST	1.66	1.66	1.66	1.66	1.66	1.66
SAN JOSE	1.63	1.63	1.63	1.63	1.63	1.63
SAN FRANCISCO	1.00	1.00	1.00	1.00	1.00	1.00
San Joaquin Air Basin						
FRESNO-OLIVE	2.16	2.17	2.16	2.17	2.16	2.16
BAKERSFIELD-CHESTER	2.39	2.39	2.39	2.39	2.38	2.37
South Coast Air Basin						
COSTA MESA-PLACENTIA	1.91	1.91	1.91	1.91	1.91	1.91
SAN BERNARDINO	4.00	4.01	4.00	4.01	3.92	3.88
AZUSA	4.28	4.30	4.28	4.30	4.21	4.18
LOS ANGELES-MAIN	2.30	2.30	2.30	2.30	2.29	2.28

Table 2-11

(continued)

Station Name	1979 no control worst case	1987 no control worst case	1979 prevail practice	1987 prevail practice	1987 curtail control	1987 planned control
(b) Annual Average of Daily Maximum						
San Diego Air Basin						
EL CAJON	5.88	6.20	5.88	6.17	5.62	5.43
SAN DIEGO-ISLAND	5.62	5.87	5.62	5.85	5.43	5.28
San Francisco Air Basin						
PITTSBURG	5.00	5.11	4.96	5.07	4.65	4.56
RICHMOND-13 ST	3.40	3.45	3.38	3.43	3.26	3.22
SAN JOSE	4.64	4.73	4.61	4.70	4.37	4.30
SAN FRANCISCO	2.10	2.10	2.10	2.10	2.09	2.09
San Joaquin Air Basin						
FRESNO-OLIVE	5.28	5.48	5.29	5.47	5.12	5.07
BAKERSFIELD-CHESTER	5.92	6.18	5.93	6.17	5.71	5.64
South Coast Air Basin						
COSTA MESA-PLACENTIA	5.38	5.43	5.38	5.43	5.08	4.94
SAN BERNARDINO	11.77	11.97	11.77	11.97	10.77	10.31
AZUSA	14.02	14.25	14.02	14.25	12.88	12.34
LOS ANGELES-MAIN	7.98	8.07	7.98	8.07	7.52	7.30

equations developed by Trijonis (1980). Tables 2-12 and 2-13 show the estimated visual range calculated for the 1979 ambient concentrations and for the different emission scenarios. It is interesting to note that visibility improves in the South Coast Air Basin under the 1987 Planned Controls Scenario compared to 1979 baseline whereas visibility is degraded somewhat in the other air basins.

2.2 HEALTH BENEFITS

The air pollutants under consideration in this study are associated with a wide variety of suspected effects on human health. Each health effect is associated with a decrease in the affected individual's well-being. It is not known exactly which individual will be affected in any population that is exposed to the air pollutants. Each individual in the exposed population is faced with an increased probability of suffering some undesirable health effect, although some individuals may be at greater risk of being affected than others due to their age, current health status or other factors. The scientific evidence is quite strong that air pollutants can have adverse effects on human health at ambient levels that have occurred or do occur, but much uncertainty remains as to exactly what effects can be expected to occur and, at what pollution levels.

The most credible and up-to-date results of previous studies have been used in this analysis to develop quantitative estimates of the health effects that could be expected under the alternative pollution control scenarios. The studies used for this purpose are epidemiological studies that examine the relationship between actual occurrences of different health effects and ambient levels of different air pollutants. The estimates of the physical health effects expected under each scenario were evaluated in dollar terms based on current available information about what individuals are willing to pay to reduce or prevent these health effects.

Table 2-14 lists the types of health effects included in the dollar estimates of the health benefits. It also lists some of the health effects that are believed to be associated with each of the pollutants but were not included

Table 2-12

Estimated Visual Range and Nitrate Concentrations for Selected Stations for the Base Period 1978 - 1980

Station Name	Visual Range (miles)	Nitrate (μg/m3)
(a) San Diego Air Basin		
EL CAJON	14.19	9.0
SAN DIEGO-ISLAND	12.28	9.0
(b) San Francisco Air Basin		
PITTSBURG	13.49	8.0
RICHMOND - 13 ST	14.26	5.0
SAN JOSE	11.66	8.0
SAN FRANCISCO	16.15	5.0
(c) San Joaquin Air Basin		
FRESNO-OLIVE	9.52	17.0
BAKERSFIELD-CHESTER	14.25	20.0
(d) South Coast Air Basin		
COSTA MESA-PLACENTIA	6.77	15.0
LAKE GREGORY	15.14	15.0
AZUSA	5.66	15.0
LOS ANGELES-MAIN	9.45	15.0

Table 2-13

Estimated Visual Range (miles) for Selected Stations for the Different Emission Scenarios

Station Name	1979 no control worst case	1987 no control worst case	1979 prevail practice	1987 prevail practice	1987 curtail control	1987 planned control
(a) San Diego Air Basin						
EL CAJON	5.80	4.18	6.94	5.02	10.70	10.83
SAN DIEGO-ISLAND	4.91	3.52	5.89	4.24	9.17	9.29
(b) San Francisco Air Basin						
PITTSBURG	9.18	8.22	10.02	8.96	12.23	12.50
RICHMOND-13 ST	9.61	8.63	10.52	9.45	12.99	13.20
SAN JOSE	9.30	8.49	9.76	8.90	10.92	11.33
SAN FRANCISCO	11.06	9.95	12.06	10.85	14.75	15.01
(c) San Joaquin Air Basin						
FRESNO-OLIVE	8.96	6.02	8.97	6.02	7.50	10.22
BAKERSFIELD-CHESTER	12.38	6.09	12.40	6.10	8.71	15.71
(d) South Coast Air Basin						
COSTA MESA-PLACENTIA	2.79	3.81	3.22	4.24	7.38	10.16
LAKE GREGORY	8.42	9.74	9.22	10.33	15.79	23.14
AZUSA	2.52	3.34	2.88	3.69	6.06	7.94
LOS ANGELES-MAIN	3.96	5.43	4.56	6.03	10.34	14.03

Table 2-14

Quantified and Unquantified Health Damages

Pollutant	Quantified Effects	Unquantified Effects
TSP/SO_4	Mortality Adult sick days (equivalent to work loss days) Adult minor restricted activity days Emergency room visits Emergency hospital admissions Aggravation of asthma symptoms	Decreased pulmonary functioning and increased respiratory illness in children Aggravation of chronic disease symptoms (other than asthma) Increased prevalence of chronic respiratory disease
0_x	Adult restricted activity days Aggravation of asthma symptoms	Aggravaqtion of chronic respiratory disease symptoms (other than asthma) Decreased athletic performance Possible increased prevalence of chronic respiratory disease
SO_2		Bronchoconstriction in individuals with chronic disease and in healthy subjects.
NO_2		Decreased pulmonary function and increased respiratory illness in children Decreased pulmonary function in asthmatics
Lead		Increased risks of cognitive and nerve impairment and anemia, especially in children at blood lead levels about 30 μg/dl Possible increased risks, especially in children, at blood lead levels between 10 and 30 μg/dl

due to lack of adequate quantitative information. Quantitative estimates of mortality and morbidity were developed for TSP/SO_4 and ozone. TSP and SO_4 were treated together because in many cases it is difficult to separate their effects. Estimates were also made concerning the number of people who would be exposed to potentially harmful levels of NO_2 and lead, although adequate information was not available to develop quantitative estimates of the number of people who could be expected to experience any given health effect. Potential effects of SO_2 were also discussed.

The quantitative estimates of the health effects associated with each scenario were obtained by applying the estimated relationship between each type of health effect and each pollutant from previous studies to the change in pollution expected under each of the scenarios. The resulting health effects estimates are shown in Tables 2-15 to 2-18. Population differences account for some of the differences between the air basins, but differences also occur because of different predicted changes in ambient pollution levels. For example, the best estimates of predicted changes in mortality in the South Coast Air Basin are smaller than those for San Francisco even though the population is larger, because the predicted changes in TSP were smaller than in San Francisco. The reverse is true of the upper bound mortality estimates due to the large predicted change in SO_4 in the South Coast Air Basin.

The wide range between the upper and lower bounds on emergency hospital admissions and emergency room visits is indicative of the uncertainty in these estimates. There is a wide variation in results from the three studies that have developed estimates of the relationship between TSP/SO_4 and these health effects. This suggests that the best estimates in these two categories are more uncertain than, for example, mortality and sick days where the results from different studies do not vary so dramatically.

The dollar estimates placed on changes in the risks of mortality were taken from wage-risk studies that have estimated the wage premium associated with on-the-job risks. Results of these studies have ranged from about $500,000 to about $5,000,000 per statistical life lost. This does not mean that an individual is willing to die in exchange for $500,000 or $5,000,000, but that

Table 2-15
Summary of Yearly Physical Benefits of Air Pollution Control to Human Health: San Fransico Bay Area Air Basin

Scenario Comparisons*

Health Effect	Comparison 1 1979 No Control	Comparison 2 1979 PP Control	Comparison 3 1987 No Control	Comparison 4 1987 PP Control	Comparison 5 1987 82 Control
Mortality (Statistical Lives)					
Best	1,244	887	1,373	989	12
Upper	1,295	923	1,431	1,032	12
Lower	0	0	0	0	0
Morbidity					
Emergency Room Visits					
Best	24,844	17,703	27,414	19,741	236
Upper	1,726,353	1,230,173	1,904,916	1,371,734	16,401
Lower	25,822	18,400	28,492	20,517	245
Emergency Hospital Admissions					
Best	978	697	1,079	777	9
Upper	191,817	136,686	211,657	152,415	1,822
Lower	0	0	0	0	0
Sick Days					
Best	6,615,915	4,714,408	7,300,217	5,256,902	62,852
Upper	19,847,748	14,143,212	21,900,676	15,770,706	188,554
Lower	2,183,253	1,555,754	2,409,073	1,734,777	20,741
Minor Restricted Activity Days					
Best	2,631,630	1,875,262	2,903,830	2,091,054	25,000
Upper	7,894,900	5,625,785	8,711,490	6,273,158	75,001
Lower	868,438	618,836	958,263	690,048	8,250
Restricted Activity Days-Asthmatics (TSP)					
Best	56,650	40,368	62,509	45,013	538
Upper	74,159	52,845	81,830	58,926	704
Lower	26,780	19,083	29,550	21,279	254
Restricted Activity Days-Asthmatics (Ozone)					
Best	3,987	3,354	8,094	7,465	1,262
Upper	5,136	4,320	10,426	9,616	1,626
Lower	1,859	1,563	3,773	3,479	588
Respiratory Restricted Activity Days					
Best	126,891	106,725	257,394	237,413	40,140
Upper	253,782	213,450	514,788	474,827	80,281
Lower	2,115	1,779	4,290	3,957	669
Person Hours Exposure to NO2 Greater Than or Equal to 25 pphm					
Best	634,994	640,390	4,552,960	4,566,351	0
People with Blood Lead Levels Greater Than or Equal to 30 μg/dl					
Best	16,789	16,789	33,036	33,036	7,579

* The scenarios comparisons are defined in Table 1-2.

Table 2-16
Summary of yearly Physical Benefits of Air Pollution Control to Human Health:
San Joaquin Valley Air Basin

Scenario Comparisons*

Health Effect	Comparison 1 1979 No Control	Comparison 2 1979 PP Control	Comparison 3 1987 No Control	Comparison 4 1987 PP Control	Comparison 5 1987 82 Control
Mortality (Statistical Lives)					
Best	381	275	434	314	1
Upper	407	299	874	753	249
Lower	0	0	0	0	0
Morbidity					
Emergency Room Visits					
Best	2,747	1,978	3,126	2,259	9
Upper	196,678	141,646	223,859	161,746	672
Lower	2,858	2,058	3,253	2,350	10
Emergency Hospital Admissions					
Best	111	80	126	91	0
Upper	21,853	15,738	24,873	17,971	75
Lower	0	0	0	0	0
Sick Days					
Best	2,033,441	1,464,466	2,314,469	1,672,282	6,953
Upper	6,100,323	4,393,398	6,943,402	5,016,847	20,857
Lower	671,035	483,274	763,774	551,853	2,294
Minor Restricted Activity Days					
Best	806,836	581,076	918,342	663,534	2,759
Upper	2,420,506	1,743,227	2,755,026	1,990,600	8,276
Lower	266,256	191,755	303,053	218,966	911
Restricted Activity Days-Asthmatics (TSP)					
Best	17,368	12,508	19,769	14,284	59
Upper	22,737	16,375	25,879	18,698	78
Lower	8,210	5,913	9,345	6,752	28
Restricited Activity Days-Asthmatics (Ozone)					
Best	1,527	1,633	7,437	7,339	917
Upper	1,967	2,103	9,579	9,454	1,181
Lower	712	761	3,466	3,421	427
Respiratory Restricted Activity Days					
Best	34,657	37,043	168,735	166,539	20,812
Upper	69,313	74,086	337,470	333,079	41,623
Lower	578	617	2,812	2,775	347
Person Hours Exposure to NO2 Greater Than or Equal to 25 pphm					
Best	0	0	0	0	0
People with Blood Lead Levels Greater Than or Equal to 30 μg/dl					
Best	7,247	7,247	15,823	15,823	4,881

* The scenarios comparisons are defined in Table 1-2.

Table 2-17
Summary of Yearly Physical Benefits of Air Pollution Control to Human Health:
South Coast Air Basin

Scenario Comparisons*

Health Effect	Comparison 1 1979 No Control	Comparison 2 1979 PP Control	Comparison 3 1987 No Control	Comparison 4 1987 PP Control	Comparison 5 1987 82 Control
Mortality (Statistical Lives)					
Best	634	461	903	736	204
Upper	4,233	3,252	3,570	2,975	805
Lower	0	0	0	0	0
Morbidity					
Emergency Room Visits					
Best	5,778	4,202	8,223	6,707	1,854
Upper	627,611	456,401	893,209	728,534	201,329
Lower	6,131	4,458	8,725	7,116	1,967
Emergency Hospital Admissions					
Best	353	256	502	409	113
Upper	69,735	50,711	99,245	80,948	22,370
Lower	0	0	0	0	0
Sick Days					
Best	3,380,597	2,458,383	4,811,202	3,924,205	1,084,457
Upper	10,141,798	7,375,144	14,433,617	11,772,614	3,253,377
Lower	1,115,598	811,266	1,587,697	1,294,988	361,171
Minor Restricted Activity Days					
Best	1,341,912	975,842	1,909,783	1,557,693	430,470
Upper	4,025,736	2,927,528	5,729,348	4,673,077	1,291,409
Lower	442,831	322,028	630,229	514,039	142,055
Restricted Activity Days-Asthmatics (TSP)					
Best	28,887	21,006	41,111	33,532	9,266
Upper	37,815	27,499	53,818	43,896	12,131
Lower	13,655	9,930	19,434	15,851	4,381
Restricted Activity Days-Asthmatics (Ozone)					
Best	28,094	28,094	63,812	63,812	17,884
Upper	36,189	36,189	82,198	82,198	23,038
Lower	13,095	13,095	29,743	29,743	8,336
Respiratory Restricted Activity Days					
Best	403,618	403,618	916,676	916,676	256,940
Upper	807,236	807,236	1,833,352	1,833,352	513,881
Lower	6,727	6,727	15,278	15,278	4,282
Person Hours Exposure to NO2 Greater Than or Equal to 25 pphm					
Best	124,923,024	124,923,024	280,858,216	280,915,512	69,881,133
People with Blood Lead Levels Greater Than or Equal to 30 $\mu g/dl$					
Best	51,728	51,730	122,867	122,746	43,632

* The scenarios comparisons are defined in Table 1-2.

Table 2-18

Summary of Yearly Physical Benefits of Air Pollution Control to Human Health:

San Diego Air Basin

Scenario Comparisons*

Health Effect	Comparison 1 1979 No Control	Comparison 2 1979 PP Control	Comparison 3 1987 No Control	Comparison 4 1987 PP Control	Comparison 5 1987 82 Control
Mortality (Statistical Lives)					
Best	403	295	511	380	6
Upper	917	666	1253	918	12
Lower	0	0	0	0	0
Morbidity					
Emergency Room Visits					
Best	2,822	2,067	3,580	2,657	43
Upper	287,899	210,910	365,314	271,146	4,381
Lower	2,983	2,185	3,785	2,809	45
Emergency Hospital Admissions					
Best	161	118	204	152	2
Upper	31,989	23,434	40,591	30,127	487
Lower	0	0	0	0	0
Sick Days					
Best	2,148,777	1,574,158	2,726,586	2,023,744	32,695
Upper	6,446,330	4,722,472	8,179,758	6,071,231	98,085
Lower	709,096	519,472	899,773	667,836	10,789
Minor Restricted Activity Days					
Best	852,584	624,588	1,081,845	802,973	12,972
Upper	2,557,751	1,873,767	3,245,534	2,408,921	38,918
Lower	281,353	206,114	357,009	264,981	4,281
Restricted Activity Days-Asthmatics (TSP)					
Best	18,353	13,445	23,288	17,285	279
Upper	24,026	17,601	30,486	22,628	366
Lower	8,676	6,356	11,009	8,171	132
Restricted Activity Days-Asthmatics (Ozone)					
Best	3501	3501	9343	8955	2337
Upper	4510	4510	12034	11536	3010
Lower	1632	1632	4355	4174	1089
Respiratory Restricted Activity Days					
Best	72,611	72,611	193,739	185,709	48,461
Upper	145,221	145,221	387,479	371,420	96,922
Lower	1,210	1,210	3,229	3,095	808
Person Hours Exposure to NO2 Greater than or Equal to 25 pphm					
Best	1,798,328	1,810,518	21,209,210	21,263,438	268,909
People with Blood Lead Levels Greater Than or Equal to 30 μg/dl					
Best	8,851	8,851	18,549	18,549	5,578

* The scenarios comparisons are defined in Table 1-2.

the amount that many individuals are willing to pay to prevent a small increase in the probability of death sums to $500,000 to $5,000,000 per life. A mid-point of $2,000,000 was selected for this analysis. There is clearly a great deal of uncertainty in this estimate, because of the wide range of values obtained in the wage-risk studies and because of differences between on-the-job risks and environmental risks. Overall, the wage-risk results are likely to be a lower bound on willingness to pay to prevent environmental risks.

The dollar estimates placed on changes in morbidity were based on the average opportunity cost of time spent sick and the average medical expenditures associated with each category of illness. These estimates can be expected to understate the total willingness to pay to prevent morbidity because they do not include any additional value an individual may place on preventing the discomfort and inconvenience associated with illness.

Table 2-19 gives the dollar estimates of the health benefits under each of the alternative control scenarios. The wide range between the upper and lower bounds in each basin is the result of the high value placed on mortality effects. Since the lower bound for the mortality effects was zero, the lower bound on total health effects includes only morbidity. The morbidity effects make up about 20 percent of the best estimates and about 30 percent of the upper bound estimates of total health benefits.

Judging from Table 2-14, it is clear that the health effects estimates reported in Table 2-19 do not include all the health effects that might be expected to occur. With the possible exception of potential increased prevalence of chronic illness, the health effects included in the dollar estimates do, however, include those expected to be associated with the greatest dollar damage: mortality, emergency room visits, hospital admissions, and sick days. From this perspective, the dollar estimates probably encompass 50% to 80% of the total health damage.

Table 2-19

Summary of Yearly Economic Estimates of Benefits of

Air Pollution Control to Human Health ($1,000 1982):

Scenario Comparisons*

Air Basin	Comparison 1 1979 No Control	Comparison 2 1979 PP Control	Comparison 3 1987 No Control	Comparison 4 1987 PP Control	Comparison 5 1987 82 Control
San Diego					
Best	985,744	723,086	1,255,737	934,083	17,289
Upper	2,558,060	1,864,279	3,434,428	2,529,089	39,524
Lower	58,698	43,039	74,682	55,514	987
South Coast					
Best	1,566,614	1,144,705	2,246,554	1,840,781	508,877
Upper	9,751,248	7,449,275	9,002,216	77,485,227	2,034,610
Lower	93,490	68,263	133,914	109,651	30,555
San Joaquin					
Best	931,040	671,119	1,065,966	772,349	4,193
Upper	1,444,784	1,053,430	2,478,225	2,037,843	502,121
Lower	55,485	39,982	63,395	45,888	229
San Francisco					
Best	3,042,393	2,168,735	3,362,666	2,423,926	30,757
Upper	5,377,482	3,833,851	5,948,833	4,291,728	54,140
Lower	184,565	131,544	203,838	146,865	1,814
4 Air Basin Total					
Best	6,525,791	4,707,645	7,930,923	5,971,139	561,116
Upper	19,131,574	14,200,835	20,863,702	16,343,887	2,630,395
Lower	392,238	282,828	475,829	357,918	33,585

* The scenarios comparisons are defined in Table 1-2.

2.3 AGRICULTURAL BENEFITS

The harmful effects of ozone and other air pollutants on California crops have been documented for at least 35 years. Most evidence suggests that the vast majority of agricultural damages are primarily due to ozone and, in a few locations, somewhat due to sulfur dioxide. Pollutant damage to crops occurs primarily through the entry of gaseous pollutants through the stomata located in the plant's leaves. Factors that affect stomatal opening (i.e. light, water, stress, and pollutant history) control the internal dose of pollutants the plant receives. The ultimate effects of pollutant exposure are foliar injury, premature senescence, reduced plant vigor and plant growth, altered product quality and reduced plant yield. The indicator of air pollution crop damage which is most useful in economic analyses is changes in yields per acre.

Nearly two dozen California crops have been identified as sensitive to air pollution at existing ambient levels. Among the list of sensitive crops are six of the top ranking cash crops in California, including grapes (#1), cotton (#2), hay (#3), lettuce (#5), oranges (#7) and tomatoes (#8). Many of these crops are grown primarily in the San Joaquin Valley and southern California regions, where some of California's highest oxidant levels have been documented, and where five of the top six agricultural counties are located. The combination of high valued, air pollution sensitive crops in locations with relatively high concentrations of ozone and other photochemical oxidants leads to potentially substantial economic impacts.

Yield functions relating air pollution to per acre crop production are used to estimate the change in yields from a change in air pollution. These yield functions are taken from the National Crop Loss Assessment Network (NCLAN) studies, summarized in Heck et al. (1983), and from a recent agricultural analysis in California by Rowe and Chestnut (1985). The crops for which damage functions are estimated include alfalfa, barley, carrots, corn, cotton, dry beans, grain hay, grapes, lettuce, pasture, potatoes, safflower, silage, tomatoes and wheat. Most of the functions are taken from the NCLAN research, which represents the broadest, most consistent and professionally defensible collection of air pollution yield functions available. These estimates are based upon carefully controlled chamber studies, generally performed in California. The alfalfa, grapes, and potatoes functions, which are not available from NCLAN, are taken from Rowe and Chestnut, who used an alternative statistical approach for estimating yield losses.

The estimated change in yields for each scenario comparison are summarized in Table 2-20. The range of estimates provided represent different changes in yield for each crop depending upon the air basin and the specific part of the air basin in which the crop is grown. In some air basins the percent change in yields across scenarios may be substantially different than in another air basin. These summary results are sufficient to indicate that the change in crop yields per acre across the scenario comparisons are generally quite small, especially for the highest value crops. This is the result of the small predicted changes in ozone levels across the scenarios.

The estimated change in yields per acre were translated into economic benefits of air pollution control by transferring results from previous applications of the California Agricultural Resources (CAR) model for the analysis of air pollution impacts to agriculture (Rowe and Chestnut 1985, and Howitt et al. 1984). The CAR model is a quadratic programming model wherein farmers and consumers are modelled to maximize their well-being subject to agricultural farm and markets conditions. Changes in yields per acre affect total production, market prices and returns on investments. Farmers are modelled to respond to these changes by optimally changing their mix and acreage of crops planted, and consumers are modelled to change the quantity of output desired as a function of market price. As a crosscheck of the transfer of CAR model economic estimates, a simple damage function approach was also used to estimate benefits. This approach multiplies the estimated change in per acre production times current levels of acres and current prices, to estimate economic impacts of changes in air pollution control. The simple damage function approach is known to overstate correct measures of air pollution control benefits by ignoring the impact of changes in per acre yields upon market prices and farm production decisions.

The economic estimates of agricultural benefits of air pollution control are summarized in Table 2-21. The "best" total estimates range up to $27.2

Table 2-20

Summary of Percent Change in California Crop Yields Across Alternative Scenario Comparisons*

Scenario Comparison Crop	(% yield improvement)				
	1	2	3	4	5
Alfalfa	0-.5	0-.5	0-1.0	0-1.0	0-.5
Barley	0-.75	0-.75	0-2	0-1.5	0-1.0
Carrots	.6	.6	3.4	3.4	1.2
Corn	0-.5	0-.5	.5-2.0	.5-2.0	0-.75
Cotton	.75	.75	3.2	3.0	1.6
Dry Beans	0-3.2	0-3.2	0-6.9	0-6.9	0-3.5
Grain Hay	0-.2	0-2	0-6	0-5	0-3
Grapes	.5-1.1	.5-1.2	1.0-5.4	1.0-5.4	.5-3.0
Lettuce	1.2-2	1.2-1.7	3.0-7.3	3.0-7.2	1.7-3.7
Pasture	0-1.3	0-2.0	.6-6.0	.6-5.8	0-3.0
Potatoes	2.4-10	2.4-10	6.2-33	6.0-32	1.9-18
Safflower	0-.6	0-.6	1.1-3.4	1.1-3.4	.5-1.5
Silage	0-.8	0-.8	.6-3.8	.6-3.7	0-2.4
Tomatoes	0-2.6	0-2.0	1.1-3.6	1.1-3.4	0-1.5
Wheat	0-2	0-2	1.3-6	1.3-5.8	.6-3

* Values calculated only for locations where the crop is grown. Ranges represent high and low figures across all locations where crop grown. See Table 6.8 for additional detail.

Table 2-21

Summary of Yearly Economic Estimates of Benefits of

Air Pollution Control to Materials ($1,000 1982)

Scenario Comparisons*

Air Basin	Comparison 1 1979 No Control	Comparison 2 1979 PP Control	Comparison 3 1987 No Control	Comparison 4 1987 PP Control	Comparison 5 1987 82 Control
San Diego					
Best Total	500	500	1,000	1,000	500
Upper Total	1,000	1,000	2,000	2,000	1,000
Lower Total	250	250	500	500	250
South Coast					
Best Total	300	300	500	500	300
Upper Total	600	600	1,000	1,000	600
Lower Total	150	150	250	250	150
San Joaquin					
Best Total	10,000	10,000	25,000	23,000	16,000
Upper Total	20,000	20,000	50,000	46,000	32,000
Lower Total	5,000	5,000	12,500	11,500	8,000
San Francisco					
Best Total	300	200	700	700	200
Upper Total	600	400	1,400	1,400	400
Lower Total	150	100	350	350	100
4 Air Basin Total					
Best Total	11,100	11,000	27,200	25,200	17,000
Upper Total	22,200	22,000	54,400	50,400	34,000
Lower Total	5,550	5,500	13,600	22,600.	8,500

* The scenarios comparisons are defined in Table 1-2.

million for scenario comparison 3. The upper bound estimates are defined as double the best estimates and the lower bound estimates are defined as one-half of the best estimates. Ozone changes are estimated to account for well over 90 percent of total benefits, with sulfur dioxide accounting for the rest. Approximately 90 percent of the benefits are estimated to occur in the San Joaquin Valley. About 60 percent of benefits are apportioned to agricultural producers and about 40 percent to consumers. It is estimated that the analysis is capturing about two-thirds or more of total agricultural benefits of air pollution control in California.

2.4 MATERIALS BENEFITS

Materials damage caused by air pollution has been widely recognized as a source of economic loss in urban areas, and to a lesser extent, in rural areas. By affecting man-made materials through many different pathways, air pollutants can reduce welfare by increasing the costs of production, maintenance, and repair. All sectors of the economy suffer economic losses through damage to materials in place, the premature replacement of vulnerable materials, and the reduced welfare caused by working in or residing in a soiled or degraded environment.

The physical effects of air pollution exposures on man-made materials vary depending upon the composition of the material and the environmental conditions characteristic of the exposure. Pollutants may cause or contribute to the surface erosion, blistering, and discoloration of paint; the corrosion and tarnishing of metals and electrical components; the fading, soiling, and reduction in the tensile strength of fabrics; and the soiling and spalling of non-metallic building materials. Because all of these effects occur, to some extent, in unpolluted environments, estimation of the economic damages associated with materials damage caused by air pollution must separate the effects of air pollution from those caused by environmental factors such as moisture, temperature, and sunlight.

Considerable research has been performed by physical scientists in an attempt to define the response of materials to a number of air pollutants. While significant and precisely defined relationships linking ambient exposures of air pollutants with materials exposed to pollutants are not available, sufficient data is available to relate a number of pollutants to materials damage, as shown in Table 2-22.

In this analysis, materials damage estimates were developed for effects caused by sulfur dioxide, ozone, and TSP. A review of the literature indicated that while nitrogen oxides may cause some materials damage, development of resistant dyes and other strategic behaviors by society have limited the damage to sensitive materials from nitrogen oxides. No damages were calculated for possible effects caused by acidic deposition or acid fog because of the inability to differentiate between acidic deposition and sulfur dioxide effects.

Estimates of materials damage caused by sulfur dioxide were developed on the basis of a number of physical and economic damage functions. The principal material receptors include zinc and paint covered metal surfaces and painted surfaces generally. Ozone damages were estimated using damage functions between annual average ozone concentrations and tire damage. The accuracy of the economic measures of damage estimated by the damage functions is limited by two factors. First, the physical damage functions apply to a small fraction of the exposed materials; and, second, they only require estimates of the material inventories exposed to air pollution in the four air basins. Because no material inventories were available, per capita economic damage estimates are based upon studies performed in Philadelphia and Boston.

Estimates of soiling damages caused by TSP were based upon a study performed by Manuel et al. (1982). This study estimated soiling damages to households by estimating a system of demand equations for the consumption and production of cleanliness that directly address household adjustments to changes in air quality. Unlike the approach used for the calculation of damages resulting from sulfur dioxide and ozone, specific damage functions relating pollutant concentrations to soiling were not estimated. Instead, the Manuel approach uses estimates of the value that households place on activities or services that are sensitive to air quality changes.

Table 2-22

Review of Materials Damage Caused by Air Pollutants

Material	Principal Damage-Causing Pollutants	Types of Damage	Other Environmental Factors	Principal Uses of Material
Paint	Sulfur Oxides Other Acid Gases Particulates	Surface Erosion Discoloration Soiling	Moisture Sun-light, Wear Microorganisms	Substrate Protection Enhance Appearance
Structured Metals	SO_x, NO_x, TSP Other Acid Gases	Corrosion Tarnishing	Moisture Salt	Variety; ex. Tanks, Buildings, Structural Supports, Roofing, Vehicles
Electrical Components	SOx, NOx, Other Acid Gases, Polymerizable Organic Gases, Particulates	Corrosion Tarnishing	Moisture Salt	Contacts, Components
Fabrics	SO2, NO2, O3, TSP Other Acid Gases	Reduced Strength Soiling, Fading	Sunlight, Mois-ture, Temperature Mildew, Wear	Variety; ex. Clothing; Home Furnishings
Plastics and Elastomers	Ozone Oxidants	Cracking Weakening	Sunlight Temperature	Variety; ex. Automobiles, Calculators, Home Furnishings
Non-Metallic Building Materials	TSP, SO2 Acidic Gases	Soiling, Discolor-ation, Rot, Surface Breakage	Moisture Freezing & Thawing Microorganisms	Structural, Decorative
Works of Art and Historic Structures	SO2, NOx, TSP Acidic Gases	Fading, Corrosion Spalling, Soiling	Moisture, Sunlight Temperature, Wear	

Table 2-23 summarizes the annual estimates of the benefits of pollution control with respect to materials damage in the four air basins. Benefits from the control of TSP are significantly greater across all control comparisons than benefits resulting from the control of sulfur dioxide or ozone. The control of TSP accounts for approximately 75-99 percent of the total best estimates depending upon the location and comparison, while the control of sulfur dioxides accounts for approximately 0-25 percent, and ozone control accounts for approximately 0-2 percent. Because TSP damage estimates do not include measures reflecting commercial soiling effects, the actual annual benefits may be considerably larger than the estimated values. The low estimates for ozone control are the result of the small predicted changes in ozone concentrations across the different control scenarios.

While precise measures of materials damage are difficult to estimate because of data and inventory limitations, the results of this study indicate that considerable benefits exist from the control of both TSP and sulfur dioxide. Given that it was not possible to incorporate the possible effects of acid deposition resulting from sulfur emissions, these benefits could be even larger.

2.5 FOREST BENEFITS

Estimates of economic measures of forest damage are based upon changes in the value of the standing stock of ponderosa and Jeffrey pine plus the aesthetic values for visual injury to ponderosa and Jeffrey pine stands. Estimated damages to the standing stock of the commercial and productive ponderosa and Jeffrey pine type are limited to National Forest lands within the four air basins. Measures of aesthetic and recreational use damage are based upon U.S.D.A. Forest Service visitor day use data for the same National Forest lands. Damages to private timber, National Parks, or non-National Forest recreation sites are not estimated.

At the present time, published evidence is only sufficient to link forest damage to ozone. While other airborne pollutants such as biologically available nitrogen compounds, toxic gases and metals, and wet and dry acid

Table 2-23

Summary of Yearly Economic Estimates of Benefits of

Air Pollution Control to Materials ($1,000 1982):

Scenario Comparisons*

Air Basin	Comparison 1 1979 No Control	Comparison 2 1979 PP Control	Comparison 3 1987 No Control	Comparison 4 1987 PP Control	Comparison 5 1987 82 Control
San Diego					
Best	377,800	276,639	481,958	357,370	5,676
Upper	729,738	534,343	930,875	690,246	10,961
Lower	25,860	18,933	33,041	24,495	390
South Coast					
Best	731,204	541,546	910,078	745,585	205,223
Upper	1,402,412	1,036,725	1,755,913	1,438,481	395,957
Lower	49,049	46,363	64,243	52,689	14,488
San Joaquin					
Best	424,400	305,881	499,968	350,065	10,296
Upper	820,050	591,035	961,512	702,966	19,724
Lower	28,750	206,570	38,424	29,365	867
San Francisco					
Best	1,316,029	1,638,867	1,456,395	1,053,094	12,488
Upper	2,525,835	1,804,532	2,797,798	2,019,032	24,097
Lower	106,225	80,472	114,992	87,154	862
4 Air Basin Total					
Best	2,849,433	2,762,933	3,348,399	2,506,114	233,675
Upper	5,478,035	3,966,635	6,446,098	4,850,725	450,739
Lower	209,884	352,342	250,700	193,703	16,607

* The scenarios comparisons are defined in Table 1-2.

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deposition may be responsible for forest declines, there is currently insufficient data to establish mechanistic or correlational relationships between ambient concentrations of these pollutants and forest responses in California.

Ozone-caused forest responses in southern California have been extensively described and reviewed by Miller et al. (1982) and others. Tree species known to be affected include the ponderosa and Jeffrey pine, and black oak. While timber production damages in this report are based upon growth and yield reductions measured in ponderosa pine, Miller (1983) also reported widespread changes in a number of fundamental ecosystem processes apparently caused by ozone exposures. These included alterations in the flow of carbon, nutrient flow, litter decomposition, moisture retention and allocation, and the relationships between forest stands and insect and fungal pathogens. Changes in these relationships can be expected to cause damage not captured in the damage to ponderosa yield including increased mortality, increased insect and pathogen propagation, ecosystem simplification and the increased risk of watershed damage and catastrophic ground fires.

Table 2-24 summarizes the physical effects believed to be caused by ozone exposures and relates those effects to changes in services valued by society. A comprehensive measure of the damages caused by ozone in the four air basins would estimate damages resulting from decrements in the provision of all of these services. By estimating damages deriving from timber and aesthetic services, only a fraction of the total possible damages were measured. In addition, timber damages were estimated for only two tree species: Ponderosa and Jeffrey pine. Because widespread changes have occurred to forested ecosystems, we believe that there are possibly substantial economic damages not estimated in this report.

The physical effects of ozone exposures to California forests were made utilizing the results of the San Bernardino National Forest Study and a number of studies conducted by the U.S.D.A. Forest Service Pest Management Division. Timber yield reductions were based upon data developed by McBride (in Miller et al., 1977) at the Rim of the World in the San Bernardino National Forest. McBride's results indicate that at 24 hour average May-September ozone

Table 2-24

Ozone Impacts to Forest Ecosystems

Environmental Effect	Affected Service	Values
Reduced growth of commercially valuable tree species	commercial timber	present and future timber values
Reduced growth of non-commercial or non-productive tree species	forest trees and understory	recreation use, aesthetic, option, and preservation values
Increased mortality and predisposition to pathogen invasion of tree species suffering reduced vigor and growth	commercial timber and forest trees and understory	present and future losses not captured through expression of growth reductions
Alteration in other ecosystem processes and functions, including: reproduction, succession water allocation and purification, and habitat provision	ecosystem diversity animal habitat provision watershed protection	use and non-use values including risk reduction and water use

concentrations of 14 pphm, the commercial volume of 30 year old ponderosa pine trees is reduced by approximately 80 percent. A damage function was fitted to this data and, in conjunction with inventory data for the commercial and productive ponderosa and Jeffrey pine types within National Forests in the different air basins, was used to estimate stumpage losses within the standing stock, (see Table 8-4 for an estimate of the total board feet of available/productive ponderosa and Jeffrey pine within each of the National Forests). To convert these growth reductions to economic damages, reductions in board feet were multiplied by the U.S.D.A. Forest Service Region 5 average stumpage price for ponderosa pine. Because the damage function was developed over a 30 year period, annual economic measures were derived by dividing total damages by 30. These estimates are recognized to be upwardly biased by their failure to incorporate market behavior.

Recreational use/aesthetic damages were estimated by extrapolating results of Crocker and Vaux (1983) over recreational visits to the National Forests within the Air Basins of interest. Crocker and Vaux estimated the value of a recreational day in three different forest quality categories using a contingent valuation survey in the San Bernardino National Forest. Using data developed in the San Bernardino National Forest Study, the ozone concentrations necessary to produce the site characteristics that were valued by Crocker and Vaux were estimated. Recreational damages were calculated, assuming that all recreation visitor days to each National Forest took place within the ponderosa-Jeffrey pine type and that recreators would express the same preferences and values as the San Bernardino sample. Estimated damage measures were calculated by classifying forest stands within the different damage classes developed by Crocker and Vaux and multiplying site visits by the daily use values reported by Crocker and Vaux.

Table 2-25 provides a summary of the calculated benefits of different air pollution control levels for recreational and commercial harvest use of forests. The estimated damages are quite small--the result of small predicted changes in the six month seasonal 24 hour average ozone levels and the limitations inherent in the current state-of-the-art for measuring forest related damages caused by regional air pollutants. In fact, no recreation related damages were estimated to occur. This is due to the limitations in

Table 2-25

Summary of Yearly Economic Estimates of Benefits of

Air Pollution Control to Materials ($1,000 1982)

Scenario Comparisons*

Air Basin/ Subeffect	Comparison 1 1979 No Control	Comparison 2 1979 PP Control	Comparison 3 1987 No Control	Comparison 4 1987 PP Control	Comparison 5 1987 82 Control
San Diego					
Upper=Lower=Best	0	0	0	0	0
South Coast					
Best	37	37	84	84	24
Upper	74	74	168	168	47
Lower	0	0	0	0	0
San Joaquin					
Best	164	264	896	884	33
Upper	329	529	1,792	1,768	67
Lower	0	0	0	0	0
San Francisco					
Best=Upper=Lower	0	0	0	0	0
4 Air Basin Total					
Best	201	301	980	968	57
Upper	403	603	1,960	1,936	114
Lower	0	0	0	0	0

* The scenarios comparisons are defined in Table 1-2.

applying the Crocker and Vaux study to the current analysis, rather than there actually being no damages. Commercial losses were estimated to occur only in the San Joaquin and the South Coast Air Basin. By assumption, the upper bound estimates for commercial losses are double the best estimates and the lower bound estimates are zero.

The best estimates of damage range from $57,000 in Comparison 5 to $968,000 in Comparison 4. It is interesting to note that the total estimates in Comparison 2 exceed those in Comparison 1, reflecting the fact that ozone values at San Joaquin monitors near the western borders of the National Forests were predicted to have the same or higher values under Scenario 4 than 2.

Many important air pollution effects on forests were not incorporated in the analysis. It is the opinion of the researchers that total economic damages to forests under the different scenarios is probably significantly larger than estimated in the present report. Substantial omissions include: the consideration of commercial species other than ponderosa and Jeffrey pine; the incorporation of other possible services that generate non-recreational use values, i.e., watershed and surface water quality; recreational use values other than those captured under "aesthetic preferences"; option-value; and a range of preservation values related to ecosystem, habitat, and species maintenance. This omission of potentially substantial values indicates that additional work on the economic valuation of forest related damages due to air pollution is a pressing need.

2.6 VISIBILITY BENEFITS

The visual aesthetic effects of air pollution are an important component of the overall impact of man-made air pollution. Small particles and gases can form plumes, layered haze, and regional haze, which can cause changes in visual range, contrast, light extinction, and color. Visibility is not something that can be directly bought or sold, but evidence suggests that people value good visibility. In urban and residential areas, a nice view can add considerable value to a property. In recreation areas people drive and hike substantial distances in order to reach certain overlooks and view the scenery.

For this analysis, visibility conditions were measured in terms of standard visual range. Visual range does not necessarily describe everything the viewer might perceive, such as color or contrast, but it is the most useful measure for this analysis because information is available about the relationship between ambient pollution levels and visual range and because most of the visual values work to date has defined and valued visibility impairment in this way. Estimates of the effect of changes in emissions of particulates, sulfates, and nitrates on average visual range were developed for each scenario. These changes in visual range were then evaluated in terms of their expected effect in residential and recreational settings.

Estimates of willingness to pay for changes in visual range in residential areas were based on studies previously conducted in Los Angeles and San Francisco and elsewhere in the country. These studies have used either the property value approach or the contingent valuation approach. Property value approaches use differences in property values between neighborhoods with different visibility levels, accounting at the same time for other differences between the neighborhoods and the property, in order to infer how much households are willing to pay for a given level of visibility. Contingent valuation approaches ask people, typically in personal interviews, how much they are willing to pay for alternative levels of visibility in the area in which they live.

Both of these types of studies obtain estimates of the value of visibility to households in the area in which they live. They do not capture potential impacts to visitors to the area and they do not include impacts on businesses that are not captured in the housing market. They also do not reflect the value that residents of one area may place on the visibility in another part of town where they may work, visit friends, etc. The effects of visibility on resident households, however, probably constitute the largest component of the benefits of protecting visibility in residential and urban areas, comprising probably 75% to 80% of all urban area visibility benefits.

The best estimates of visibility benefits for resident households based on previous studies were $8 per year per mile change in visual range for the South Coast and the San Joaquin air basins. The upper bound was $21 and the lower bound was $4, based on the range of results found in studies in the South Coast area and elsewhere in the country. The best estimates for San Francisco and San Diego were $16 per year per mile change in visual range, reflecting evidence that residents of San Francisco and San Diego place a higher value on visibility than do people in the South Coast and San Joaquin. The upper bound was $35 and the lower bound was $7 based on the range of results found in studies in the San Francisco area and elsewhere in the country.

The estimates of value for protecting visibility in recreational settings were based on contingent valuation studies that have been conducted in parks and recreation areas in several parts of the country, although none of these studies were conducted in California. In these studies, visitors to these areas are typically asked what they would be willing to pay to have certain visibility conditions during their visit to the park. These studies therefore provide some information about the value to park visitors of protecting visibility for their visit to the park, but do not reflect any value visitors and non-visitors may place on simply knowing that visibility in parks and recreation areas is being protected. Previous research has found that these kinds of "preservation values" may be substantial, but adequate quantitative information was not available to allow estimation of preservation values for this analysis.

Studies on the value of visibility to park visitors have found that the daily willingness to pay per mile change in visual range varies from about $.03 to about $.15 per mile per visitor party, and is at the higher end of the range when the initial visual range level is lower. The best estimate used for the scenarios in this analysis was close to the upper bound of $.15 since the visual range levels in the study area are typically under 20 miles. Since most of the previous studies on the value of visibility in receation areas were conducted in areas where visual range is typically over 50 miles, even the upper bound estimates provided here probably understate the value of visibility in the four California air basins.

Annual visitation for 1983 at national and state parks and recreation areas and national forests in the four air basins were used for the calculation of visibility related recreation benefits. This can be expected to understate the total impact of visibility on recreation because locally operated parks and recreation in private areas was not included. This limitation and the fact that the estimates do not include preservation values suggest that the estimates presented here for the benefits of protecting visibility in recreation areas comprise probably only 25% to 50% of all recreation related visibility benefits in the study areas.

Table 2-26 gives the annual estimates of the benefits of pollution control with respect to visibility in the four air basins. These estimates include both the residential and recreational benefits. In each of the air basins the recreation estimates are less than 10% of the total, primarily because more people are affected more often in residential settings than in recreation settings. The upper bounds are about two times the best estimates and the lower bounds are about one-half the best estimates.

2.7 SUMMARY AND COMPARISON TO PREVIOUS STUDIES

2.7.1 Summary

Table 2-27 provides a summary of the total of all estimated benefits of air pollution control across all damage categories by air basin and by scenario. The best estimate of total benefits range from approximately $1-12 billion per year depending upon the scenario examined. The relative importance of different effects categories is illustrated in Table 2-28, where the best estimate for scenario comparison 1 is reported by effects category and air basin. Human health benefits comprise about 67 percent of the total, with mortality equalling roughly 54 percent of the total.

The uncertainty in the estimates is quite large as indicated by the large range from the upper to lower bound estimates in Table 2-27. The upper bound estimates are somewhat more than double the best estimates. The lower bound

Table 2-26

Summary of Yearly Economic Estimates of Benefits of Air Pollution Control to Visibility ($1,000 1982)

Scenario Comparisons*

Air Basin	Comparison 1 1979 No Control	Comparison 2 1979 PP Control	Comparison 3 1987 No Control	Comparison 4 1987 PP Control	Comparison 5 1987 82 Control
San Diego					
Best	84,696	73,378	66,567	58,163	1,309
Upper	184,294	159,673	144,726	126,547	2,847
Lower	36,829	31,910	28,920	25,288	569
South Coast					
Best	178,392	159,563	299,092	280,039	136,020
Upper	459,699	411,299	770,599	721,443	350,163
Lower	87,491	78,279	146,668	137,313	6,650
San Joaquin					
Best	10,708	10,603	56,483	56,448	40,525
Upper	26,544	26,282	139,356	139,269	99,992
Lower	5,059	5,009	26,561	26,545	19,060
San Francisco					
Best	122,524	98,608	129,007	107,549	10,570
Upper	266,123	214,194	280,269	233,687	23,022
Lower	53,182	42,805	5,610	46,700	4,601
4 Air Basin Total					
Best	396,320	342,152	551,149	502,199	184,361
Upper	936,660	811,448	1,334,950	1,220,946	476,024
Lower	182,561	158,003	258,159	235,846	30,880

* The scenarios comparisons are defined in Table 1-2.

Table 2-27

Summary of Yearly Economic Estimates of Benefits of

Air Pollution Control to all Effects Categories ($1,000 1982)

Scenario Comparisons*

Air Basin	Comparison 1 1979 No Control	Comparison 2 1979 PP Control	Comparison 3 1987 No Control	Comparison 4 1987 PP Control	Comparison 5 1987 82 Control
San Diego					
Best	1,448,740	1,073,603	1,805,262	1,350,616	24,774
Upper	3,473,092	2,559,295	4,512,029	3,347,882	54,332
Lower	121,637	94,132	137,143	105,797	2,196
South Coast					
Best	2,476,547	1,846,151	3,456,308	2,866,989	850,444
Upper	11,614,033	8,897,973	11,529,896	9,646,319	2,781,377
Lower	230,180	193,055	345,075	299,903	51,843
San Joaquin					
Best	1,376,312	997,867	1,648,313	1,202,746	71,047
Upper	2,311,707	1,691,276	3,630,885	2,927,846	653,904
Lower	94,294	256,561	140,880	113,298	28,156
San Francisco					
Best	4,481,246	3,906,410	4,948,768	3,585,269	54,015
Upper	8,170,040	5,852,977	9,028,300	6,545,847	101,659
Lower	344,122	254,921	324,790	281,069	7,377
4 Air Basin Total					
Best	9,782,845	7,824,031	11,858,651	9,005,620	996,217
Upper	25,568,872	19,001,521	28,701,110	22,467,894	3,591,272
Lower	790,233	798,669	947,888	800,067	89,572

* The scenarios comparisons are defined in Table 1-2.

Table 2-28

Summary of Yearly Best Estimate of Total Economic Estimates of Benefits of Air Pollution Control for Scenario Comparisons 1 ($1,000 1982)

Air Basin	Human Health	Agriculture	Materials	Forests	Visibility
San Diego	985,744	500	377,800	0	84,696
South Coast	1,566,614	300	731,204	37	178,392
San Joaquin	931,040	10,000	424,400	164	10,708
San Francisco	3,042,393	300	1,316,029	0	122,524
4 Air Basin Total	6,525,791	11,100	2,849,433	201	396,320
Subjective estimates of percentage of damages included*	50-80%	greater than 66%	33-75%	less than 20%	60-80%

* These numbers represent subjective judgement of the authors, made with great reservation, to provide a sense of the potential value of captured versus uncaptured values. The judgements are also contingent upon the acceptance of the ambient pollutant estimates, and are made recognizing the uncertainty in the point estimates, upper and lower bound estimates are provided in corresponding tables.

estimates are only 8 to 10 percent of the best estimates. These large ranges are the primary result of the uncertainties in measuring and valuing mortality, which dominate the analysis. The upper bound estimate for mortality effects includes potential effects of SO_4, while the best estimate is based on TSP only. The lower bound estimate for mortality effects was set to zero to reflect the uncertainty and controversy in epidemiology studies of mortality impacts from air pollution, although a higher lower bound could also be defended as appropriate.

If uncertainty in the value of mortality effects were also included, the upper bound on mortality effects would double again, and the total across all damage categories would increase by about 75 percent. This is because the range of professionally defensible estimates of the value of a statistical life range up to over $5 million per statistical life, more than twice the $2 million per statistical life used in this analysis. However, the combined use of both the upper bound on estimated impacts and the upper bound economic valuation estimate was felt to be unreasonable. The dominance of mortality impacts and valuation on the total social value of air pollution control, combined with the uncertainty in the measurement of these impacts and values, suggests the importance of continuing research to refine these health impacts and valuation estimates.

Table 2-28 also reports a subjective judgement by the authors of the range of economic values, by effect category, that have been included in the quantification. These can only be interpreted as professional judgement based on evidence outlined in Chapters 5-9. The assessment suggests that of the effects categories considered, the quantitative estimation of physical and economic benefit measures related to forested ecosystems are the least satisfactory. Given the omissions in the effects categories considered, plus the omitted pollutants and effects categories (see Section 1.3), the reported estimates may be capturing only 50 percent of all air pollution control benefits.

2.7.1 Comparisons With Previous Studies

The results of this effort can be roughly compared to preceding efforts, but this comparison is limited by the lack of consistency in the definition of scenarios, locations and other study design characteristics.

The study by Freeman (1982) is among the most cited of similiar efforts. Freeman computes economic measures of benefits from air pollution control nationwide under the scenario of a 20 percent decrease in TSP and SO_2. In addition, he assumes a 20 percent decrease in the number of days on which the ozone standard is violated for the calculation of agricultural damage. Freeman asserts this was roughly equivalent to the changes that occurred from 1970 to 1978. Freeman's estimates, adjusted to 1982 dollars, are $33 billion. Freeman used $1 million as the value of a statistical life. For comparison to our effort, Freeman's total estimates would be aproximately $55 billion when adjusted to the $2 million value of a statistical life figure used in our study. Using these adjustments, Freeman's lower and upper bound range of values would be aproximately $10 to $110 billion.

Health values in Freeman's study, as adjusted above, account for just over 80 percent of total air pollution control benefits. Again using the adjusted numbers, Freeman's materials damage (including soiling) are about 10 percent of the total, versus 29 percent in this study, and vegetation and aesthetics account for 7 percent of the total versus about 4 percent in the current study. The primary difference in these percentages is likely to be due to differences in the relative rate of change in study pollutants considered in the two efforts, particularly for ozone, and that recent literature has been used in the California analysis herein that results in a lower expected rate of change in mortality from changes in TSP and sulfates (on the order of one-half) which therefore reduces the relative share of total economic values relating to health effects.

While it is difficult to make comparisons between the absolute magnitude of the estimates in the Freeman study and this study, we attempt to do so. Our scenario comparison number 2 is the closest to Freeman's assumptions of a 20 percent decrease in TSP, SO_2 and ozone. In scenario comparison 2 the population weighted decrease in ambient concentrations of these pollutants are roughly 22 percent, 16 percent and 0 percent respectively. Because ozone, lead and NO_2 are associated with relatively small values in either study (largely due to small changes in ozone and to the lack of quantitative research to use) these differences are of secondary significance in the comparison between the total estimates of the two studies. Using our scenario comparison 2, Freeman's adjusted estimate of $55 billion nationwide is about seven times our Calfiornia study area estimate of $7.8 billion, while the national population is roughly 10-11 times as large as the California study area population. Consequently, our estimates, on a per capita basis, are on the order of one and a half times larger than Freeman's adjusted nationwide estimates. This difference does not seem unreasonable. Much of the United States has considerably lower pollution levels than our study areas, a fact Freeman accounts for in his estimates. Other factors that account for the differences between the studies include differences in included and excluded effects, pollutants, scenarios and other variations in approach. If the mortality to TSP and sulfates relationships used by Freeman were used in this study, the per capita benefits in this study would be 3 to 4 times larger than in the Freeman work.

A second related study was performed by Fisher et al. (1979, also reported in Hamilton, 1979) for six urban areas in California. The study examined and valued selected effects of 10, 25, and 50 percent changes in selected pollutants. The urban areas included Fresno, Los Angeles-Long Beach, Sacramento, San Bernardino-Riverside-Ontario, San Diego, and San Francisco-Oakland. The 1977 population of the Fisher et al. study area is roughly two-thirds of the 1980 population of our study area. For comparison's sake we will compare Fisher et al.'s 25 percent decrease numbers to our Scenario 2 estimates and will inflate their numbers to 1982 dollars. Fisher et al.'s estimates for soiling and materials damage are on the order of $400 million, while our estimates are over $2 billion. Fisher et al.'s estimates of human health impacts, which use the lowest published value of a statistical life value of $300,000 are only .6 billion. When adjusted to the $2 million value of a statistical life estimate, their estimates increase to $4 billion, which is close to our $5 billion for all health effects. Although, as with Freeman, their estimated mortality impacts from TSP and sulfates are substantially larger than those here (roughly double). Fisher et al. provided only suggestive estimates on agricultural and forest losses and no visibility estimates.

Several inmportant research design characteristics primarily account for the significant differences between the Fisher et al. study and the current effort. The current effort encompassed 50 percent more population, and more pollutants were considered. Fisher et al. generally considered TSP and/or SO_2 in determining damages in any effects category. Fisher et al. were able to utilize less literature as a basis for their estimates. As a result important effects included in the current effort were omitted in their analysis. These include the effects of other pollutants on the categories considered, morbidity effects, visibility effects, and many materials and soiling damages. Their analysis is also not always consistent in defining the percent change in air pollution across different measures of ambient conditions, which generally reduces their results. For example, a 25 percent change in the annual average will be associated with a much larger change in the peak values used in some of their calculations. Finally Fisher et al. do not provide any upper and lower bound estimates.

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