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The Health and Related Economic Benefits of Attaining Healthful Air in the San Joaquin Valley

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All statements and conclusions in this study are solely those of the authors.

ACRONYMS

ARB	California Air Resources Board
CAAQS	California Ambient Air Quality Standards
COI	Cost of illness
C-R	Concentration response function
EPA	Environmental Protection Agency
FRM	Federal Reference Method
MRAD	Minor restricted activity day
NAAQS	National Ambient Air Quality Standards
ppb	Parts per billion
ppm	Parts per million
REHEX	Regional Human Exposure Model
SAB-HEES	Science Advisory Board Health and Ecological Effects Subcommittee
SJVAB	San Joaquin Valley Air Basin
SYMVAL	Symptom Valuation Model
VSL	Value of a statistical life
WLD	Work loss day
WTP	Willingness to pay

I. EXECUTIVE SUMMARY

Overview

Only the Los Angeles and Houston regions have air pollution levels that rival those in the San Joaquin Valley (SJV). Historical and current air quality levels for ozone and fine particles ($PM_{2.5}$) in the San Joaquin Valley (SJV) are unhealthful. The air basin is classified by the U. S. Environmental Protection Agency (EPA) as a serious nonattainment area for both ozone and $PM_{2.5}$.

Both the federal government and California have set health-based air quality standards for ozone and fine particles because there is wide concurrence that these pollutants pose a serious risk to health. Adverse effects clearly associated with ozone range from school absences and hospitalizations to symptoms that limit normal daily activity. $PM_{2.5}$ exposure is tied to a range of effects from premature death and the onset of chronic bronchitis to work loss days and respiratory symptoms.

Between 1990 and 2004 ambient ozone levels in the San Joaquin Valley exceeded the health-based 8-hour National Ambient Air Quality Standard (NAAQS) on from more than 80 to nearly 135 days a year. Ozone levels are typically elevated in the summer months, so this suggests that air is unhealthful on most summer days. Not only is the NAAQS frequently violated, but between 2001 and 2004 the maximum 8-hour concentration was 65% above the standard. In much of California ozone levels have fallen steadily over a period of years, but this is not the case in the SJV, which is a concern.

While the region has achieved reductions in coarser particle (PM_{10}) levels, concentrations of the more dangerous fine particles - $PM_{2.5}$ - remain unhealthful. To meet the maximum 24-hour standard levels must fall by more than 10%, and annual average concentrations must fall by nearly 30%. Attaining the California standard (CAAQS) requires a drop of 50%. These health-based standards will be very difficult to achieve in the SJV.

The primary objective of this study is to assess the health and related economic benefits that will result from attainment of the ozone and $PM_{2.5}$ standards, to the extent that they can be quantified.

Results

Valley-wide, the economic benefits of meeting the federal $PM_{2.5}$ and ozone standards average nearly $1,000 *per person per year*, or a total of more than $3 billion. This gain represents the following:

- 460 fewer premature deaths among those age 30 and older
- 325 fewer new cases of chronic bronchitis
- 188,400 fewer days of reduced activity in adults
- 260 fewer hospital admissions
- 23,300 fewer asthma attacks

- 188,000 fewer days of school absence
- 3,230 fewer cases of acute bronchitis in children
- 3,000 fewer work loss days
- More than 17,000 fewer days of respiratory symptoms in children

To place the reduction in premature deaths in perspective, attaining the federal $PM_{2.5}$ standard would be the equivalent of reducing motor vehicle deaths by over 60% Valley-wide, and by more than 70% in Fresno and Kern Counties.

Research Approach

A well-established three-stage approach is used to determine the benefits of attaining the ozone and $PM_{2.5}$ air quality standards by identifying and quantifying the links between air quality and exposure, exposure and ill health, and avoiding ill health and the associated economic loss.

The Regional Human Exposure Model (REHEX) was developed to estimate a population's exposure to concentrations above the air quality standards. This model accounts for the spatial and temporal pollution patterns across a region, which is important because pollution patterns vary significantly across a large area. Exposure for the population in the SJV is estimated by 5X5 kilometer grids relative to pollution levels averaged from 2002-2004. Averaging is necessary to reduce the influence of weather anomalies that do not accurately represent longer term trends in air quality. REHEX generates estimates of exposure by county, by age, and by ethnic group as defined by the U.S. Bureau of the Census. These exposure estimates are then coupled with concentration-response functions from the health science literature to calculate how many fewer adverse health effects and premature deaths would be expected if the 2004 population instantaneously experienced attainment of the NAAQS.

Finally, economic values are applied to the avoided health effects and extended lives to estimate in dollar terms the social value of more healthful air. These values are based on the cost of treating illness and the expressed value that people place on avoiding illness and premature death.

Implications

Residents of the San Joaquin Valley face significant public health risks from the present unhealthful levels of ozone and fine particles. This is in addition to other health challenges, including a high rate of poverty, which exceeds 30% in Fresno County, compared to a statewide rate below 20%. The region overall would experience substantial economic and health gains from effective policies to reduce pollution levels. For the more populous and more polluted areas in Kern and Fresno Counties, this is even more pronounced. Attaining the California air quality standards, which are more protective of health, would double the benefits listed above.

The adverse impacts of air pollution are not distributed equally. Both Hispanics and non-Hispanic blacks are exposed to more days when the health-based standards are violated.

Residents of Fresno and Kern Counties experience many more days than the Valley-wide average.

Because ozone is elevated during the summer months, and the $PM_{2.5}$ 24-hr standard is typically violated more frequently in the winter months, there is no “clean” season in this region.

As the population continues to increase, with associated increases in vehicle traffic and economic activity, the gains from attaining the health-based air quality standards will grow, but also become more difficult to achieve. Identifying and acting on opportunities now would produce substantial gains to the people of the Valley.

II. INTRODUCTION

II.1 Background

Only the Los Angeles and Houston regions have air pollution levels that rival those in the San Joaquin Valley (SJV). Historical and current air quality levels for ozone and fine particles ($PM_{2.5}$) in the SJV are unhealthful. The air basin is classified by the U. S. Environmental Protection Agency (EPA) as a serious nonattainment area for both ozone and $PM_{2.5}$.

Both the federal government and California have set health-based air quality standards for ozone and fine particles ($PM_{2.5}$) because there is wide concurrence that these pollutants pose a serious risk to health. Adverse effects clearly associated with ozone range from school absences and hospitalizations to symptoms that limit normal daily activity. $PM_{2.5}$ exposure is tied to a range of effects from premature death and the onset of chronic bronchitis to work loss days and respiratory symptoms.

Between 1990 and 2004 ambient ozone levels in the San Joaquin Valley exceeded the health-based 8-hour National Ambient Air Quality Standard (NAAQS) on from more than 80 to nearly 135 days a year. Ozone levels are typically elevated in the summer months, so this suggests that air is unhealthful on most summer days. Not only is the NAAQS frequently violated, but between 2001 and 2004 the maximum 8-hour concentration was 65% above the standard. In much of California ozone levels have fallen steadily over a period of years, but this is not the case in the SJV, which is a concern.

While the region has achieved reductions in coarser particle (PM_{10}) levels, concentrations of the more dangerous fine particles - $PM_{2.5}$ - remain unhealthful. To meet the maximum 24-hour standard levels must fall by more than 10%, and annual average concentrations must fall by nearly 30%. Attaining the California standard (CAAQS) requires a drop of 50%. These health-based standards will be very difficult to achieve in the SJV.

II.2 Objectives of this Study

The primary objective of this study is to assess the health and related economic benefits that will result from attainment of the ozone and $PM_{2.5}$ standards, to the extent that they can be quantified with present knowledge. The gains from attaining both the federal and state standards are estimated, although it is generally recognized that attaining the state standards will be especially difficult in some parts of the SJV[1].

II. 3 Overview of the Research Approach

A well-established three-stage approach is used to determine the benefits of attaining the ozone and $PM_{2.5}$ air quality standards by identifying and quantifying the links between air quality and exposure, exposure and ill health, and avoiding ill health and the associated economic loss.

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[1] Because attainment of the NAAQS is therefore the more policy-relevant outcome over the next decade, the California results are included in the Appendix while the Federal results are discussed in the body of this report.

The Regional Human Exposure Model (REHEX) was initially developed in 1989 to estimate a population's exposure to concentrations above the air quality standards. This model accounts for the spatial and temporal pollution patterns across a region, which is important because pollution patterns vary significantly across a large area. Here, exposure for the population in the SJV is estimated by 5X5 kilometer grids relative to pollution levels averaged from 2002-2004. Averaging is necessary to reduce the influence of weather anomalies that do not accurately represent longer term trends in air quality. REHEX generates estimates of exposure by county, by age, and by ethnic group as defined by the U.S. Bureau of the Census. These exposure estimates are then coupled with concentration-response functions from the health science literature to calculate how many fewer adverse health effects and premature deaths would be expected if the 2004 population instantaneously experienced attainment of the NAAQS and the CAAQS.

Finally, economic values are applied to the avoided health effects and extended lives to estimate in dollar terms the social value of more healthful air. Specific values are derived from the economics literature and have all undergone peer-review, both as part of that literature and as part of scientific and technical assessments of which values are most appropriate for valuing health in relation to air pollution exposure.

III. POPULATION EXPOSURE TO OZONE AND PARTICULATE MATTER

III.1 The Exposure Assessment Approach

Accurate estimates of human exposure to inhaled air pollutants are necessary for appraisal of the health risks these pollutants pose and for the design and implementation of strategies to control and limit those risks. Most exposure estimates are based on measured concentrations of outdoor (ambient) air concentrations obtained at fixed-site air monitoring stations. Ambient concentrations are used as surrogates for personal exposure. Personal exposure to air pollutants depends not only on ambient concentrations in locations or microenvironments (home, work, schools, vehicles, etc.) where individuals spend time, but also on the amount of time individuals spend in the microenvironments and on the concentrations in the microenvironments. Microenvironment concentrations are affected not only by infiltration of outdoor air, but also by indoor sources and indoor pollutant deposition. Outdoor concentrations vary spatially and temporally and are affected by proximity to local outdoor sources, which may result in concentrations that deviate significantly from ambient concentrations at the nearest air monitoring stations.

Despite the recognized discrepancies between personal exposure and exposures based on ambient concentrations obtained from fixed-site air monitoring stations, compliance with the National Ambient Air Quality Standards (NAAQS) depends exclusively on outdoor measurements of pollutants. The NAAQS are intended to protect public health with an adequate margin of safety. Most epidemiologic studies of air pollution health effects use ambient concentrations as surrogates for actual population exposures. In fact, virtually all concentration-response relationships from large population studies use ambient concentrations as the exposure input parameter. Several studies have argued that air pollution exposure should be separated into ambient and non-ambient components for health effects research because even though ambient concentrations are not highly correlated with personal exposures to non-ambient concentrations or total concentrations, they are highly correlated with ambient-generated concentrations (Wilson et al. 2000; Ebelt et al. 2003). Therefore, ambient concentrations may be used in epidemiologic studies as appropriate surrogates for exposure to ambient-generated concentrations.

The exposure assessment approach for this study is constrained to rely on ambient concentrations not only because the ambient air quality database is the only database with sufficient spatial and temporal coverage to address the San Joaquin Valley Air Basin (SJVAB) population, but also because this study requires quantification of the benefits of attainment of the ambient-based NAAQS and must rely on the ambient-based concentration-response relationships from the health science literature to quantify those benefits. The approach is also guided by the concern for spatial resolution of both the population and ambient concentrations.

The population exposure assessment approach used for this study involves representing the population and ambient concentrations on a spatial grid covering the SJVAB. Each grid square is 5 km x 5 km in size. Five-kilometer resolution is sufficient to capture the urban- and regional-scale spatial gradients in between air quality monitoring stations, which are located from 10 to 50 km apart in the SJVAB. This resolution is insufficient to capture intra-urban spatial variations associated with close proximity to major roadways or stationary emission sources. Spatially and temporally resolved air quality and population data are used in the

Regional Human Exposure (REHEX) model (Lurmann et al. 1989; Lurmann et al. 1994; Fruin et al. 2001) to quantify the frequency of population exposure to various levels of ambient ozone and particulate matter concentrations over multi-year periods.

III.2 Population

We developed gridded population data for use in the exposure assessment for eight age groups: < 1 year, 1 year, 2-4 years, 5-17 years, 18-21 years, 22-29 years, 30-64 years, and > 64 years, and four racial groups: white non-Hispanic, black non-Hispanic, other non-Hispanic, and Hispanic. The age groups were defined by the concentration-response relationships chosen for use in the benefits evaluation. Racial groups were defined by the U.S. Census. Not all the population data breakdowns by age and race were available at fine resolution in the 2000 U.S. Census database. County, census tract, and block-group levels of population data were used in determining the disaggregated block-group population data. County-level age distribution data were used to estimate the block-group population of children ages < 1, 1, and 2-4 years by racial group. Census-tract level data were used to estimate the block-group population of other age groups for black non-Hispanic and other non-Hispanic groups. Block-group data were used directly for the other age groups for white non-Hispanics and Hispanics. The block-group population data for each age-racial group were spatially allocated to 5 km x 5 km grid squares assuming uniform population density within each block group. The spatial allocation was performed with STI's GIS tools (ESRI ARCGIS Version 9.0). Grids on the boundaries between counties were assigned to the county with the most surface area within the grid.

The modeling grid and gridded 2000 total population data are shown in Figure III-1. These data show that high population densities (> 1,200 km^{-2}) occur in the major cities, such as Lodi, Stockton, Modesto, Turlock, Fresno, Visalia, and Bakersfield, as expected. A total of 1,708 grids located within the SJVAB were used for assessing exposure. Grid squares with extremely low population density (below 1 person per km^{-2} or 25 persons per grid) were not included; they were large in number of grids but accounted for less than 1% of the total population in the aggregate.

The baseline period selected for exposure assessment was 2002 through 2004 (see Section III.3). Population data for 2000 were projected to 2004 to be consistent with the baseline period for air quality data. County-specific growth rates based on the growth from 1990 to 2000 (as reported in the U.S. Census (www.censuscope.org)) were used to scale up the 2000 data to represent the 2004 population. Within each county, the population of all age and racial groups was scaled uniformly. The 2004 populations were estimated as 6.6, 7.8, 6.9, 14.3, 7.5, 10.2, 6.8, and 8.2% higher than the 2000 populations for San Joaquin, Stanislaus, Merced, Madera, Fresno, Kings, Tulare, and Kern Counties, respectively. The estimated total population in the region is 3.34 million persons in 2004. As shown in Table III-1, about 25% of the residents live in Fresno County and another 35% lived in San Joaquin and Kern Counties. Adults, ages 30 to 64 years, are the largest age group (41%), followed by children ages 5 to 17 (23.5%). Likewise, as shown in Table III-2, whites and Hispanics are the largest racial/ethnic groups.

The SJVAB is experiencing high population growth; however, we have not included the likely population growth beyond 2004 in our estimates of the benefits of attaining air quality standards in the future. This approach is conservative in that it results in underestimation of the likely benefits and avoids having to specify when the region will actually reach its air quality goals. Because the population is growing at about 2% per year, the benefits are likely to be 16% to 20% greater than estimated if attainment is achieved in 8 to 10 years.

Estimates of the population of children attending school were also needed to determine the benefits of reduced school absences associated with air quality improvements. Public school enrollment and schedules for the 2005-2006 school year were obtained from SJVAB school districts. They indicated that 83.5% and 16.5% of public school children attended schools on traditional and year-round schedules, respectively. The majority of traditional school schedules extended for 9½ months, from mid-August through May. Additional attendance data indicated that 4% of children, ages 5-17 years, attended private schools. We did not have private school schedules or information on summer school attendance for public or private schools. Because private school attendance was low, no distinction was made between the schedules of public and private school students. Ten percent of traditional-schedule school children were assumed to attend summer school, which is a low estimate based on our analysis of data for Southern California (Hall et al. 2003). The population of children, ages 5-17 years, attending school in the non-summer period (mid-August through May) was estimated at 96.6% based on the sum of children in schools with traditional schedules (83.5%) and year-round schedules (9½ /12 x 16.5%=13.1%). The population of children, ages 5-17 years, attending school in the summer period (June through mid-August) was estimated at 21.4% based on the sum of children in schools with year-round schedules (13.1%) and children with traditional school schedules who were attending summer school (8.3%).

Table III-1. 2004 SJVAB population by county and age group.

Region	<1 Year	1 Year	2-4 Years	5-17 Years	18-21 Years	22-29 Years	30-64 Years	>64 Years	All Ages
San Joaquin County	8,531	8,711	27,796	130,408	35,154	59,283	242,360	61,762	574,005
Stanislaus County	6,888	7,174	22,569	107,166	27,466	49,096	196,460	49,545	466,364
Merced County	3,695	3,766	12,084	56,898	13,956	23,726	87,393	21,109	222,627
Madera County	2,213	2,368	7,458	34,300	8,902	16,663	69,805	17,348	159,057
Fresno County	13,284	13,433	41,667	191,295	54,309	94,551	322,881	81,231	812,651
Kings County	2,136	2,155	6,525	28,336	8,921	19,533	59,417	10,211	137,234
Tulare County	6,706	6,538	20,750	95,226	24,841	42,301	150,254	37,576	384,192
Kern County	9,979	10,045	30,830	140,112	36,682	68,071	238,230	50,337	584,286
Air Basin (Persons)	53,432	54,190	169,679	783,741	210,231	373,224	1,366,800	329,119	3,340,416
Air Basin (Percent)	1.6%	1.6%	5.1%	23.5%	6.3%	11.2%	40.9%	9.9%	100%

Table III-2. 2004 SJVAB population by county and racial/ethnic groups.

Region	White[a]	Black[a]	Hispanic	Other[a]	Total (Persons)	Total (Percent)
San Joaquin County	279,855	38,694	182,293	73,163	574,005	17.2%
Stanislaus County	277,637	11,506	151,213	26,008	466,364	14%
Merced County	93,073	8,264	104,208	17,082	222,627	6.7%
Madera County	80,534	6,125	66,249	6,148	159,057	4.8%
Fresno County	324,342	42,887	370,591	74,831	812,651	24.3%
Kings County	58,828	10,991	61,403	6,012	137,234	4.1%
Tulare County	163,320	5,459	199,331	16,082	384,192	11.5%
Kern County	265,643	35,044	256,831	26,769	584,286	17.5%
Air Basin (persons)	1,543,201	158,968	1,392,180	246,066	3,340,416	100%
Air Basin (percent)	46.2%	4.8%	41.7%	7.4%	100%	

[a] Non-Hispanic whites, blacks and other.

III.3 Current Ambient Air Quality

III.3.1 Current Conditions Relative to the Air Quality Standards

Historical and current ambient air quality conditions for ozone and particulate matter in the SJVAB are unhealthful. Concentrations exceed the health-based NAAQS and the more stringent California Ambient Air Quality Standards (CAAQS). The SJVAB is classified as a serious nonattainment area by the U.S. Environmental Protection Agency (EPA) for ozone and $PM_{2.5}$. The most relevant NAAQS for ozone is the 8-hour daily maximum standard of 0.08 parts per million (ppm) or 80 parts per billion (ppb). It has essentially replaced the 1-hour daily maximum ozone standard of 0.12 ppm, which is less stringent[2] in the SJVAB. Federal standards exist for maximum 24-hour average and annual average $PM_{2.5}$ and PM_{10}. The 65 $\mu g/m^3$ 24-hour $PM_{2.5}$ standard and 15 $\mu g/m^3$ annual $PM_{2.5}$ standard are generally more stringent than the 150 $\mu g/m^3$ 24-hour PM_{10} standard and 50 $\mu g/m^3$ annual PM_{10} standard. The SJVAB will reach federal attainment when the more stringent federal standards are reached. Thus, this study focuses on the 8-hour ozone standard and the 24-hour and annual average $PM_{2.5}$ standards. Compliance with the California standards (a 70 ppb 8-hour daily maximum ozone and a 12 $\mu g/m^3$ annual average $PM_{2.5}$ standard) is addressed in the appendix.

The frequency and severity of exceedances of the 8-hour daily maximum ozone standard are illustrated in Figures III-2 and III-3. The SJVAB measurement data show that the ambient concentrations exceeded the level of the standard on 82 to 134 days per year between 1990 and 2004. This high frequency indicates that most days during the summer were ozone exceedance days. Unlike other parts of California, the frequency of exceedances is not declining with time in the SJVAB, which is a concern for residents and government agencies. During the 2001-2004 time period, the maximum 8-hour concentration was 132 ppb or 65% above the level of the standard. The highest 8-hour concentrations occur most frequently southeast of Bakersfield at the Arvin air monitoring station. Similarly high concentrations can occur downwind of Fresno. The 8-hour NAAQS is achieved when the three-year average of the annual fourth-highest concentration is below the level of the standard. The three-year average of the annual fourth-highest concentration was 116 ppb for 2002-2004 and 113 ppb for 2003-2005. This value is referred to as the ozone design value for the baseline period. We chose to use 2002-2004 for our baseline period because we wanted to use the same period for ozone and $PM_{2.5}$, and annual $PM_{2.5}$ data for 2005 were not available when we initiated this study. Thus, attainment of the 8-hour NAAQS is expected when the annual fourth-highest concentration is reduced from 116 ppb to 84.99 ppb. Note, 84.99 ppb is used instead of 80 ppb because of agency guidance on rounding concentrations for compliance with the "0.08 ppm" standard. Attainment of the ozone standard requires a 27% decrease in the design value. However, because there is a global background concentration of about 40 ppb, the required reduction in ozone in excess of the background level is 41% to reach attainment.

Even though the region achieved compliance with the PM_{10} NAAQS in the 2003-2005 time period, $PM_{2.5}$ air quality conditions remain unhealthful. Figure III-4 shows the 98th percentile 24-hour average and the annual average $PM_{2.5}$ concentration in 2002-2004 at key

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[2] Here, stringent means more limiting in terms of the difficulty of attainment.

monitoring stations. The highest 24-hour average $PM_{2.5}$ concentration in 2002 was 91 μg/m^3 at Corcoran, which is 40% above the level of the standard. The highest annual average concentration in 2002 was 24 μg/m^3 in Bakersfield at the Golden State Highway air monitoring station, where the 24-hour maximum was also high (85 μg/m^3). High $PM_{2.5}$ concentrations were also observed in the middle portion of the SJVAB as indicated by the data for Fresno, Visalia, and Corcoran. High 24-hour concentrations tend to occur in the fall and winter in this area. Like the ozone standard, the $PM_{2.5}$ standards are based on three-year periods. The annual $PM_{2.5}$ NAAQS is achieved when the three-year averaged annual mean $PM_{2.5}$ concentration is less than or equal to 15 μg/m^3. The 24-hour $PM_{2.5}$ standard is achieved when the three-year average of the annual 98th percentile values at each $PM_{2.5}$ monitoring site is less than or equal to 65 μg/m^3. The $PM_{2.5}$ design values are 20.6 and 73.2 μg/m^3 for the annual average and 24-hour standards, respectively. The design values are based on data from Bakersfield for the 2002-2004 baseline period. It should be noted that EPA's $PM_{2.5}$ attainment document suggests a lower 24-hour design value for this area, but we believe that 73.2 μg/m^3 is the correct value because it is based on the exact same data that were used to determine the 20.6 μg/m^3 annual average (also cited by EPA). The current design values indicate that maximum 24-hour and annual averages need to decrease by 11% and 27% to achieve compliance with the federal standards. The San Joaquin Valley Air Pollution Control Agency is charged with developing an air quality management plan by 2008 that will result in attainment of the $PM_{2.5}$ NAAQS by 2013.

California has an annual average $PM_{2.5}$ standard of 12 μg/m^3, never to be exceeded. Compliance with this standard would require the 2002 annual concentration of 24 μg/m^3 in Bakersfield be reduced by 50%. This health-based standard will be very difficult to achieve in the SJVAB.

III.3.2 Spatial Mapping

Ambient air quality data from California's network of monitoring stations were used to spatially map concentrations to the exposure grids. Measured concentration data were spatially interpolated and extrapolated to provide estimates of concentrations at each grid shown in Figure III-1. The locations of air monitoring stations on the exposure grid are shown in Figure III-5. For the 2002-2004 baseline period, hourly ozone data were available for 27 stations within the SJVAB and daily $PM_{2.5}$ data were available once every three days for 14 stations within the SJVAB. Ozone and $PM_{2.5}$ data from stations within the grid and within 150 km of the grid boundaries were incorporated in the air quality database used for mapping. The ozone data were used to create maps of hourly concentrations for each day of the baseline period (1,096 days and 26,304 maps). Daily $PM_{2.5}$ data collected using the Federal Reference Method (FRM) were available on an every-day basis at several sites and on an every-third-day sampling schedule at many more sites. Spatial mapping was not feasible using data only from sites with every-day sampling. The spatial mapping of daily $PM_{2.5}$ concentrations was performed using the FRM data on days when the every-third-day data were available in addition to the every-day data (~116 days per year). Annual average $PM_{2.5}$ concentrations were calculated from the FRM data using EPA's methodology (i.e., annual average = average of quarterly averages) and mapped for each year.

The spatial mapping method assigns exposure grid concentrations from the nearest station if the station is located within 3 km of the center of the exposure grid. If no stations with valid data are located with 3 km of the center of the exposure grid, the concentration is calculated by inverse-distance squared weighting of the concentrations from the four stations closest to the center of the exposure grid, provided all stations are located within 100 km of the exposure grid center. In areas with sparse network coverage, the algorithm may be applied with fewer than four stations (i.e., one to three stations). This method is very similar to the method used by EPA on its AIRNow web site (www.epa.gov/airnow) for mapping air quality indices. Examples of the maps created with this method are shown in Figure III-6. They show the spatially mapped annual average $PM_{2.5}$ concentrations for 2002, 2003, and 2004. The annual $PM_{2.5}$ concentrations are estimated to vary smoothly across the region, with higher concentrations in the southern regions and in the urban areas. The maps of daily $PM_{2.5}$ and hourly ozone maps often have more spatial variability than these examples because they reflect the day-to-day variations in meteorological conditions that greatly influence the spatial patterns. The ozone maps also reflect the greater spatial coverage of monitoring station data for ozone than for $PM_{2.5}$.

III.4 Future Ambient Air Quality

For purposes of this exposure analysis, we are interested in the spatial and temporal distribution of ambient concentrations for a three-year period in which the air quality standard is attained. Attainment of the standard means that the design value is reduced to the level of the standard. Two methods are available to estimate future-year air quality conditions. One method involved the application of detailed meteorological, emissions, and air quality models to estimate the distributions of future concentrations under specific emission scenarios. Such models are used to develop emission control strategies to reach attainment in the air quality plans. Typically, the detailed models are applied for relatively short periods (less than two weeks per episode) rather than multi-year periods. The resources (time and budget) required to apply this method for a three-year period in the SJVAB are far greater than available for this study; hence, this method is not feasible for the present study.

The second method involves the application of the simple linear rollback model shown below.

$$C_{xyt}^{Future} = C_{Bkgrd} + \left(C_{xyt}^{Base} - C_{Bkgrd}\right)\left(\frac{C_{Std} - C_{Bkgrd}}{C_{Max} - C_{Bkgrd}}\right) \qquad \text{if } C_{xyt}^{Base} \geq C_{Bkgrd} \qquad (1)$$

$$C_{xyt}^{Future} = C_{xyt}^{Base} \qquad \text{if } C_{xyt}^{Base} < C_{Bkgrd} \qquad (2)$$

where C_{xyt}^{Future} = the future concentration at location *x,y*, and time *t,*

C_{xyt}^{Base} = the baseline period concentration at location *x,y*, and time *t,*

C_{Bkgrd} = the background concentration,

C_{Max} = the design value concentration, and

C_{Std} = the air quality standard threshold concentration.

This method assumes that future changes in concentrations in excess of the background concentration will linearly track changes in the current or baseline maximum concentration (minus the background concentration). It assumes that concentrations in excess of the background concentration with attainment will be linearly reduced in proportion to the ratio of the standard (adjusted for background) to the design value (also adjusted for background). Concentrations at or below the background level are assumed to be unaffected by changes in emissions. The rollback model is a very simple air quality model that ignores much of the detailed knowledge of the atmospheric chemistry and physics that influence concentrations, yet it is probably the most suitable model when the specific emission control measures needed to reach attainment in a region are not yet identified. The reason is that attainment can be achieved with different sets of control measures that will produce different spatial and temporal patterns of concentrations; and without knowledge of the specific path to attainment in the SJVAB, it is best to keep the projection method as simple as possible.

The parameters used to project the distributions of concentrations with attainment are shown in Table III-3. They project that future ozone levels in excess of the background would be 59% of current levels. Similarly, the future 24-hour and annual $PM_{2.5}$ concentrations in excess of the background are estimated as 89% and 65% of current levels. These factors are applied to the spatially mapped baseline-period concentrations to generate the future-year spatial maps of concentrations for the same time period (three years).

Table III-3. Parameters used to estimate ambient ozone and $PM_{2.5}$ concentrations with attainment.

Pollutant/Parameter	Design Value	Attainment Level	Background Concentration
Ozone 8-hour daily Maximum NAAQS	116.7 ppb	84.99 ppb	40 ppb
Ozone 8-hour daily Maximum CAAQS	132.5 ppb	74.99 ppb	40 ppb
$PM_{2.5}$ 24-hour Average NAAQS	73.2 $\mu g/m^3$	65.49 $\mu g/m^3$	6 $\mu g/m^3$
$PM_{2.5}$ Annual Average NAAQS	20.6 $\mu g/m^3$	15.49 $\mu g/m^3$	6 $\mu g/m^3$
$PM_{2.5}$ Annual Average CAAQS	24.1 $\mu g/m^3$	12.49 $\mu g/m^3$	6 $\mu g/m^3$

III.5 Current and Future Population Exposure Estimates

The REHEX model was applied using population and air quality data for the SJVAB to estimate the population exposure to ozone and $PM_{2.5}$ in the baseline period and the future with attainment. The population exposure to air pollution was quantified not only in terms of the exposure metrics relevant to the air quality standards, but also in terms of the exposure metrics used in the concentration-response relationships reported in the health science literature. The exposure metrics for ozone include the 1-hour daily maximum, the 2-week average 1-hour daily maximum, the 5-hour daily maximum, the 8-hour daily maximum, and the 24-hour average concentrations. Certain concentration-response relationships use 8-hour 10 a.m. to 6 p.m. ozone rather than 8-hour daily maximum ozone; the two metrics are almost indistinguishable in the

SJVAB. The exposure metrics for $PM_{2.5}$ include the 24-hour average concentration and the annual average concentrations.

Most of the concentration-response relationships used in this study apply to all days of the year. The school-absence concentration-response relationship applies to exposures on the day preceding the school absence. For this analysis, exposures occurring on Fridays and Saturdays were excluded as well as the day preceding each holiday.

III.5.1 Exposure Frequency Distributions

The overall frequency distributions of daily exposure for the SJVAB population are shown in Figures III-7 through III-12. The total number of person-days of exposure is large for this region and time period, 1.2 billion per year (3.34 million x 365 days), so the distributions are presented on a logarithmic scale. The figures show the number of person-days of exposures per year to concentrations above various concentration thresholds. They illustrate a four to five order of magnitude difference between the person-days of exposure to the highest levels observed in the SJVAB and the person-days of exposure to levels above the background concentrations. Figure III-13 shows the estimated number of persons exposed to annual average $PM_{2.5}$ concentrations above various concentration thresholds in the SJVAB. The daily and annual distributions show large differences in the frequency of exposure between the baseline and NAAQS attainment scenario.

III.5.2 Spatial Distributions of Exposure

The estimated spatial distribution of exposure to ozone concentrations above 100, 85, and 70 ppb are shown in Figure III-14 through III-16. They show that the highest number of person-days of exposure occur in and around Bakersfield, Fresno, Visalia, Merced, and Turlock in the 2002-2004 period. The size of the region with more than 300,000 person-days of exposure per year per grid greatly increases as the exposure concentration threshold increases from 70 to 85 ppb and from 85 to 100 ppb. The maps also show a dramatic decrease in estimated exposures above 85 ppb under the 8-hour ozone NAAQS attainment scenario. No exposures above 85 ppb are estimated for most of the SJVAB with attainment; only residents in and around Fresno, and downwind of Bakersfield are estimated to have about one day of exposure per year above the statistically based 8-hour NAAQS threshold of 85 ppb with attainment.

Maps of the estimated population exposure to 24-hour average $PM_{2.5}$ concentrations above 65 and 40 $\mu g/m^3$ are shown in Figures III-17 and III-18. The 40 $\mu g/m^3$ threshold is used here because it is the daily $PM_{2.5}$ threshold for sensitive groups. The maps show that the number of exposures above 40 and 65 $\mu g/m^3$ in Bakersfield, Fresno, Visalia, and Modesto are higher than elsewhere. Residents in these urban areas are estimated to have one or two days per year of exposure to $PM_{2.5}$ concentrations above 65 $\mu g/m^3$ with attainment of the 24-hour NAAQS.

The spatial distributions of population exposures to annual average $PM_{2.5}$ concentrations above 18, 15, and 12 $\mu g/m^3$ are shown in Figure III-19 through III-21, respectively. The number of residents estimated to be exposed to annual average $PM_{2.5}$ concentrations above 15 $\mu g/m^3$ is greater in Fresno, Visalia, and Bakersfield than elsewhere in the SJVAB. With attainment of the NAAQS, the area with residents exposed to concentrations above 15 $\mu g/m^3$ shrinks substantially from that in the baseline period. However, the number of exposures and size of areas where residents are exposed to concentrations above 12 $\mu g/m^3$—a level considered more protective of public health than 15 $\mu g/m^3$—are quite similar in the baseline and NAAQS attainment cases.

III.5.3 Exposure Frequency by County, Age Group, and Racial/Ethnic Group

III.5.3.1 8-hour Daily Maximum Ozone Exposures

The estimated number of exposures to 8-hour daily maximum ozone concentrations above 70, 85, and 100 ppb are listed in Table III-4 for the individual counties and for the whole air basin. The REHEX model estimates 10 million, 69 million, and 235 million person-days of exposures per year to 8-hour concentrations above 100, 85, and 70 ppb, respectively, in the air basin in the baseline period. With NAAQS attainment, the estimated person-days of exposures per year above 85 ppb decrease from 69 million to 293 thousand in the air basin. The estimated exposures above 70 ppb decrease from 235 million to 34 million with attainment. Zero exposures to 8-hour ozone above 100 ppb are estimated with NAAQS attainment. The highest number of exposures to ozone above 85 ppb is estimated to occur in Fresno County where there are 25 million person-days in the baseline period and 211 thousand person-days with attainment. These changes represent large reductions in unhealthful ozone exposures.

When these results are normalized by the population, they indicate the average number of days per year that residents are exposed to ambient concentrations above various thresholds. Table III-5 shows that the number of days per year above 100, 85, and 70 ppb 8-hour daily maximum ozone is estimated as 3, 21, and 70 days for the entire air basin population in 2002-2004. In Kern and Fresno Counties, residents are estimated to be exposed to more than 85 ppb 8-hour daily maximum ozone concentrations on 31 and 34 days per year on average, respectively. In contrast, residents of San Joaquin and Stanislaus Counties are estimated to be exposed to more than 85 ppb 8-hour ozone on 0 and 5 days per year, respectively, in the baseline period. The average number of days per year with population exposure to 8-hour ozone above 70 ppb in the baseline period is 10, 29, 67, 81, 94, 79, 100, and 106 days in San Joaquin, Stanislaus, Merced, Madera, Fresno, Kings, Tulare, and Kern Counties, respectively, and 70 in the air basin, on average. With NAAQS attainment, the average number of days of population exposure above 85 and 70 ppb is estimated to be less than 1 and 10 days, respectively, for the air basin population.

Table III-6 and III-7 show the number of person-days and days of exposure to the 8-hour ozone concentration thresholds by age group. Because the age distributions are fairly similar across the region, the estimated number of days above 70 and 85 ppb is similar for the different age groups. Even without consideration of human time activity, the model results indicate children are exposed slightly more frequently than adults over age 30 in the SJVAB. For example, children under age 5 are exposed to ozone above 70 ppb on 72 days per year compared to 68 days per year for adults over age 64.

Table III-8 and III-9 show the number of person-days and days of exposure to the 8-hour ozone concentration thresholds by racial/ethnic group. The results show that Hispanics are exposed more frequently than other racial groups to 8-hour ozone levels above 70 and 85 ppb.

For example, the estimated number of days above 85 ppb is 18, 19, 20, and 23 days per year for other races, blacks, whites, and Hispanics, respectively, in the air basin. Spatial differences in the population racial/ethnic makeup for different counties and within counties are responsible the differences in exposure frequencies. Figure III-22 and III-23 illustrate the differences in estimated frequency of exposures by ethnic/racial group within the air basin and by ethnic/racial group within each county. They show that the ranking of exposure frequencies by ethnic/racial group varies considerably by county. For example, in Merced and Madera Counties, black and other non-white racial groups have slightly higher exposure frequencies than whites and Hispanics.

III.5.3.2 One-hour, 5-hour, and 24-hour Ozone Exposures

Population exposure to ozone was also estimated for 1-hour and 5-hour daily maxima and 24-hour average for use in the health benefits evaluation. Tables III-10 through III-13 summarize the exposure results for these metrics. The number of person-days of exposure to 5-hour daily maximum ozone concentrations above 90 and 100 ppb was 71 million and 23 million in the baseline period for the SJVAB. With NAAQS attainment, the estimated number of person-days of exposure drops to 320 thousand and zero above 90 and 100 ppb, respectively. The number of person-days of exposure to 1-hour daily maximum concentrations above 100 and 120 ppb was 46 million and 6 million, respectively, in the baseline period and 250 thousand and zero with attainment, respectively. Results are also presented in Table III-12 for exposure to the 2-week average 1-hour daily maximum concentrations, which are similar to the exposure results for the 5-hour daily maximum concentrations. The results suggest residents of Fresno County have the highest number of person-days of exposure to high 1-hour and 5-hour daily maximum concentrations in the SJVAB, which is consistent with the results for high 8-hour daily maximum concentrations.

Many of the concentration-response relationships rely on the 24-hour average ozone values which are substantially lower than the 1-hour and 8-hour daily maxima, and do not receive much attention because they are not the focus of the air quality standards. In the SJVAB, there are an estimated 97 million person-days of exposure per year to 24-hour average ozone concentrations above 50 ppb. There are also 17 million and 1.7 million person-days of exposure to 24-hour average ozone concentrations above 60 and 70 ppb, respectively, in the 2002-2004 baseline period. With attainment, 19 million, 650 thousand, and zero person-days of exposure to 24-hour average ozone concentrations above 50, 60, and 70 ppb are estimated to occur in the air basin annually. Residents of Kern, Tulare, and Fresno Counties are estimated to have about the same number (4 million) of persons-days of exposure to 24-hour ozone above 60 ppb in the baseline period. With attainment, residents of Kern and Tulare Counties are estimated to have 387 thousand and 198 thousand person-days above 60 ppb compared to 15 thousand person-days for residents of Fresno County. The relative importance of 24-hour exposures appears higher in the southern portion of the SJVAB.

The results for alternate ozone exposure metrics suggest attainment of the NAAQS is likely to produce major reductions in all ozone metrics relevant to protection of public health, not just the 8-hour daily maximum exposures which are the focus of the standard. Because the relationships between the metrics vary between counties and between the urban-core, suburban, and rural areas within counties, the relative benefits of attainment are likely to vary with the metric selected for a particular evaluation.

III.5.3.3 24-hour Average $PM_{2.5}$ Exposures

The estimated number of exposures of the SJVAB population to 24-hour average $PM_{2.5}$ concentrations above 40 and 65 $\mu g/m^3$ are shown in Tables III-14 through III-18. The results for the baseline period indicate about 88 million and 8.7 million person-days of exposure to concentrations above 40 and 65 $\mu g/m^3$ occur annually in the SJVAB. The majority of the exposures occur in Fresno and Kern Counties. The average number of days of exposure to concentrations above 40 $\mu g/m^3$ is 32 and 39 days per year in Fresno and Kern Counties, respectively, compared to 26 days per year on average in the SJVAB in 2002-2004. The estimated average number of days of exposure above the 65 $\mu g/m^3$ level of the NAAQS ranges from zero in San Joaquin County to 4 per year in Fresno and Kern Counties.

With attainment of the 24-hour NAAQS, which is much less stringent than the annual NAAQS, SJVAB population exposure to 24-hour average $PM_{2.5}$ concentrations above 40 and 65 $\mu g/m^3$ is estimated to be 61 million and 3.2 million person-days per year above 40 and 65 $\mu g/m^3$, respectively. This represents a 63% decrease in person-days of exposure above the level of the standard on average. On a county basis, the model estimates 36%, 38%, 73%, 86%, 93%, 97%, 100%, and 100% fewer person-days of $PM_{2.5}$ exposure above 65 $\mu g/m^3$ will occur with attainment of the 24-hour NAAQS in Kern, Stanislaus, Fresno, Tulare, Kings, San Joaquin, Merced, and Madera Counties, respectively. On average, residents of Kern and Stanislaus Counties are likely to experience two days per year with 24-hour average $PM_{2.5}$ concentrations above 65 $\mu g/m^3$ after attainment of the 24-hour NAAQS.

Table III-17 and III-18, and Figures III-24 and III-25 show the results for estimated daily $PM_{2.5}$ exposures by racial/ethnic group. They suggest that blacks and Hispanics have slightly more frequent exposure to elevated $PM_{2.5}$ concentrations than whites and other races in the SJVAB. The largest difference in racial/ethnic group $PM_{2.5}$ exposure frequencies occurs in Madera County.

III.5.3.4 Annual Average $PM_{2.5}$ Exposures

The estimated annual average exposure of SJVAB residents to $PM_{2.5}$ in the 2002-2004 and with attainment is summarized in Tables III-19 through III-24. The exposure calculations indicate 98%, 74%, and 33% of the SJVAB population are exposed to annual average $PM_{2.5}$ concentrations above 12, 15, and 18 $\mu g/m^3$. Approximately 31%, 33%, 67%, 74%, 85%, 95%, 97%, and 98% of the residents of San Joaquin, Stanislaus, Merced, Kern, Madera, Tulare, Fresno, and Kings counties are exposed to annual average $PM_{2.5}$ concentrations above 15 $\mu g/m^3$ in the baseline period, respectively. Similarly, 77% and 72% of residents, ages less than 1 year and greater than 64 years, are estimated to be exposed to annual average $PM_{2.5}$ concentrations above 15 $\mu g/m^3$ in the baseline period. Approximately 70%, 71%, 77%, and 79% of white, other race, black, and Hispanic residents are estimated to be exposed to annual $PM_{2.5}$ concentrations above the NAAQS threshold.

With attainment of the annual NAAQS, the model estimates that 0%, 16%, and 73% of the SJVAB population will be exposed to annual concentrations above 12, 15, and 18 µg/m^3, respectively. No exposures to annual $PM_{2.5}$ concentrations above 15 µg/m^3 are estimated to occur in the northern half of the SJVAB (i.e., in San Joaquin, Stanislaus, Merced, and Madera Counties) with attainment. However, approximately 16%, 22%, 27%, and 30% of residents in Kern, Fresno, Tulare, and Kings Counties, respectively, are estimated to be exposed to annual $PM_{2.5}$ concentrations above 15 µg/m^3 under the NAAQS attainment scenario. Also, the majority (73% to 96%) of residents of Madera, Fresno, Kings, Tulare, and Kern Counties are estimated to be exposed to annual $PM_{2.5}$ concentrations above 12 µg/m^3 with annual NAAQS attainment. Nevertheless, the estimated reduction of population exposed to annual $PM_{2.5}$ greater than 15 µg/m^3 from 2.5 million people (74% of the population) in 2002-2004 to 520 thousand people (16% of the population) with NAAQS attainment represents a substantial improvement in air quality and a decrease in associated PM-related health effects (including premature mortality) for residents of the SJVAB.

Table III-4. The estimated SJVAB population exposure to 8-hour daily maximum ozone concentrations above 70, 85, and 100 ppb in the 2002-2004 baseline period and with NAAQS attainment by region.

Region	Person-days of Exposure Per Year in the 2002 – 2004 Baseline Period			Person-days of Exposure Per Year With NAAQS Attainment[a]	
	O_3 >70 ppb	O_3 >85 ppb	O_3 >100 ppb	O_3 >70 ppb	O_3 >85 ppb
SJV Air Basin	234,844,480	68,981,644	10,263,964	33,831,101	292,757
San Joaquin County	5,841,758	272,877	4,696	5,314	0
Stanislaus County	13,347,645	2,102,079	80,860	684,963	0
Merced County	14,889,810	4,626,388	577,332	2,480,696	362
Madera County	12,873,744	3,436,128	538,545	1,625,296	45,633
Fresno County	76,781,642	25,510,837	5,514,961	14,614,819	211,237
Kings County	10,824,809	2,567,352	301,929	1,030,735	0
Tulare County	38,564,534	10,767,642	1,071,872	4,520,114	62
Kern County	61,720,538	19,698,341	2,173,769	8,869,163	35,463

[a] Person-days of exposure to ozone >100 ppb is estimated to be zero with attainment of the 8-hour NAAQS.

Table III-5. The estimated average number of days per year that the SJVAB population is exposed to 8-hour daily maximum ozone concentrations above 70, 85, and 100 ppb in the 2002-2004 baseline period and with NAAQS attainment by region.

Region	Average No. of Days of Exposure Per Year in the 2002 – 2004 Baseline Period			Average No. of Days of Exposure Per Year With NAAQS Attainment[a]	
	O_3 >70 ppb	O_3 >85 ppb	O_3 >100 ppb	O_3 >70 ppb	O_3 >85 ppb
SJV Air Basin	70	21	3	10	<1
San Joaquin County	10	0	0	0	0
Stanislaus County	29	5	0	1	0
Merced County	67	21	3	11	0
Madera County	81	22	3	10	<1
Fresno County	94	31	7	18	<1
Kings County	79	19	2	8	0
Tulare County	100	28	3	12	0
Kern County	106	34	4	15	<1

[a] Days of exposure to ozone >100 ppb is estimated to be zero with attainment of the 8-hour NAAQS.

Table III-6. The estimated SJVAB population exposure to 8-hour daily maximum ozone concentrations above 70, 85, and 100 ppb in the 2002-2004 baseline period and with NAAQS attainment by age group.

Age Group	Person-days of Exposure Per Year in the 2002 – 2004 Baseline Period			Person-days of Exposure Per Year With NAAQS Attainment[a]	
	O_3 >70 ppb	O_3 >85 ppb	O_3 >100 ppb	O_3 >70 ppb	O_3 >85 ppb
Children <1 Year	3,872,925	1,149,985	172,609	567,167	4,836
Children 1 Year	3,904,201	1,157,552	173,809	570,946	4,906
Children 2-4 Years	12,166,958	3,604,316	540,086	1,776,968	15,228
Children 5-17 Years	55,807,112	16,494,003	2,450,812	8,112,525	68,028
Adults 18-21 Years	14,998,006	4,434,267	671,161	2,193,130	18,836
Adults 22-29 Years	26,760,371	7,873,702	1,181,929	3,870,832	34,088
Adults 30-64 Years	94,822,090	27,664,729	4,073,571	13,487,462	119,204
Adults >64 Years	22,512,583	6,603,022	999,976	3,252,038	27,631

[a] Person-days of exposure to ozone >100 ppb is estimated to be zero with attainment of the 8-hour NAAQS.

Table III-7. The estimated average number of days per year that the SJVAB population is exposed to 8-hour daily maximum ozone concentrations above 70, 85, and 100 ppb in the 2002-2004 baseline period and with NAAQS attainment by age groups.

Age Group	Average No. of Days of Exposure Per Year in the 2002 – 2004 Baseline Period			Average No. of Days of Exposure Per Year With NAAQS Attainment[a]	
	O_3 >70 ppb	O_3 >85 ppb	O_3 >100 ppb	O_3 >70 ppb	O_3 >85 ppb
Children <1 Year	72	22	3	11	<1
Children 1 Year	72	21	3	11	<1
Children 2-4 Years	72	21	3	10	<1
Children 5-17 Years	71	21	3	10	<1
Adults 18-21 Years	71	21	3	10	<1
Adults 22-29 Years	72	21	3	10	<1
Adults 30-64 Years	69	20	3	10	<1
Adults >64 Years	68	20	3	10	<1

[a] Days of exposure to ozone >100 ppb is estimated to be zero with attainment of the 8-hour NAAQS.

Table III-8. The estimated SJVAB population exposure to 8-hour daily maximum ozone concentrations above 70, 85, and 100 ppb in the 2002-2004 baseline period and with NAAQS attainment by racial or ethnic group.

Group	Person-days of Exposure Per Year in the 2002 – 2004 Baseline Period			Person-days of Exposure Per Year With NAAQS Attainment[a]	
	O_3 >70 ppb	O_3 >85 ppb	O_3 >100 ppb	O_3 >70 ppb	O_3 >85 ppb
White	102,861,799	29,522,344	4,173,191	14,088,345	124,941
Black	10,879,697	3,206,169	472,590	1,589,282	15,431
Hispanic	106,115,459	31,818,857	4,882,668	15,876,654	128,487
Other	15,151,622	4,482,164	741,113	2,298,549	24,006

[a] Person-days of exposure to ozone >100 ppb is estimated to be zero with attainment of the 8-hour NAAQS.

Table III-9. The estimated average number of days per year the SJVAB population is exposed to 8-hour daily maximum ozone concentrations above 70, 85, and 100 ppb in the 2002-2004 baseline period and with NAAQS attainment by racial or ethnic group.

Group	Average No. of Days of Exposure Per Year in the 2002 – 2004 Baseline Period			Average No. of Days of Exposure Per Year With NAAQS Attainment[a]	
	O_3 >70 ppb	O_3 >85 ppb	O_3 >100 ppb	O_3 >70 ppb	O_3 >85 ppb
White	67	19	3	9	<1
Black	68	20	3	10	<1
Hispanic	76	23	4	11	<1
Other	62	18	3	9	<1

[a] Days of exposure to ozone >100 ppb is estimated to be zero with attainment of the 8-hour NAAQS.

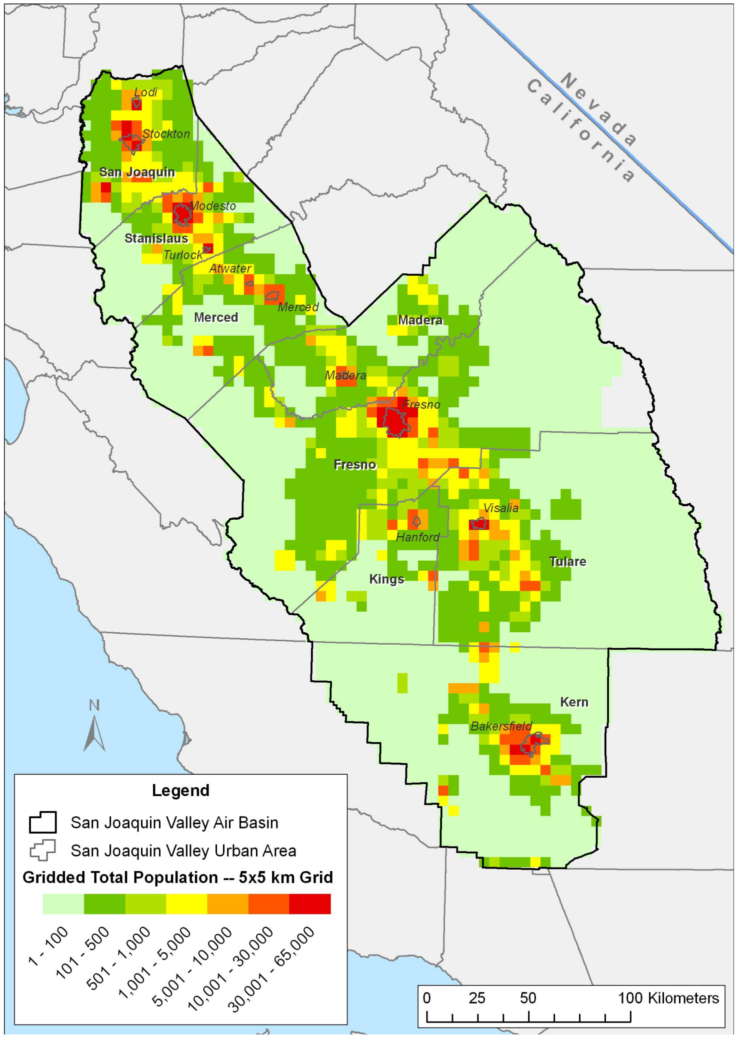
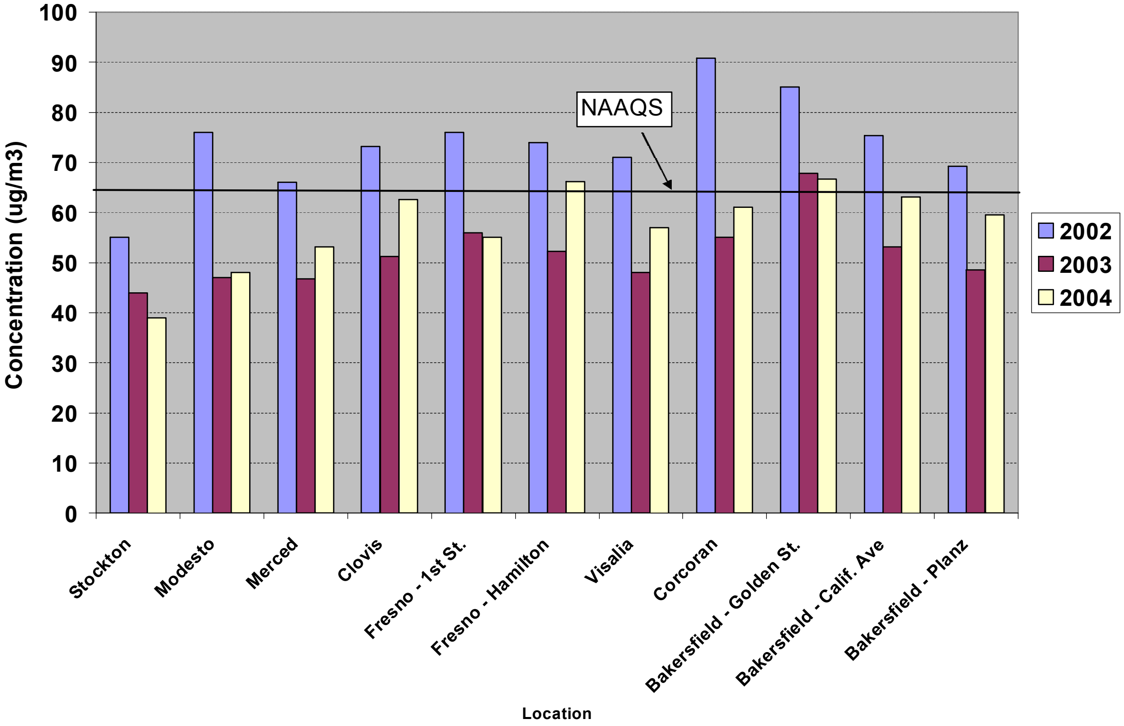


Figure III-1. Grid system used for assignment of population and air quality data in the SJVAB and gridded total population data for 2000.

Figure III-2. The frequency of ozone NAAQS exceedance days in the SJVAB from 1990 to 2004. The figure shows the number of days per year with 8-hour daily maximum ozone concentrations at one or more stations above the NAAQS and the 7-year average frequency (from SJVAPCD 2005).

Figure III-3. The frequency and severity of ozone NAAQS exceedances in the SJVAB from 2001 to 2004. Severity is indicated by the NAAQS exceedance percentage on the worst day of the year (from SJVAPCD 2005).



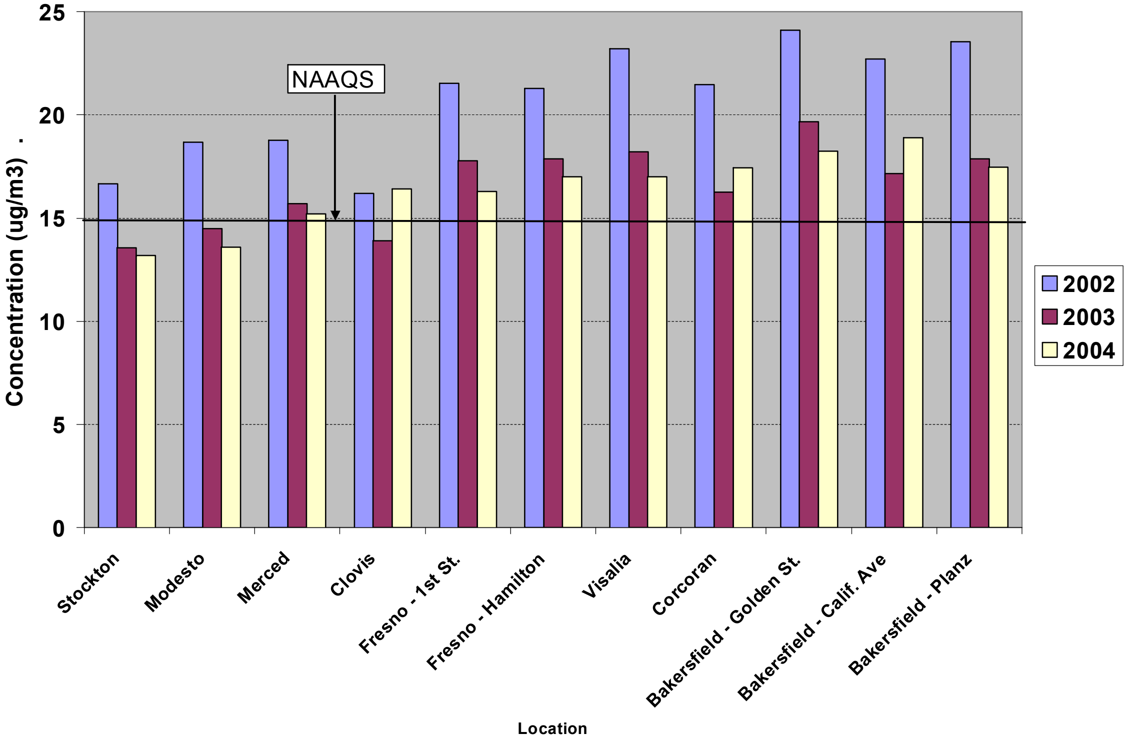


Figure III-4. Ninety-eighth percentile 24-hour average $PM_{2.5}$ concentrations (top) and annual average $PM_{2.5}$ concentrations (bottom) at key monitoring stations in the SJVAB in 2002 – 2004.

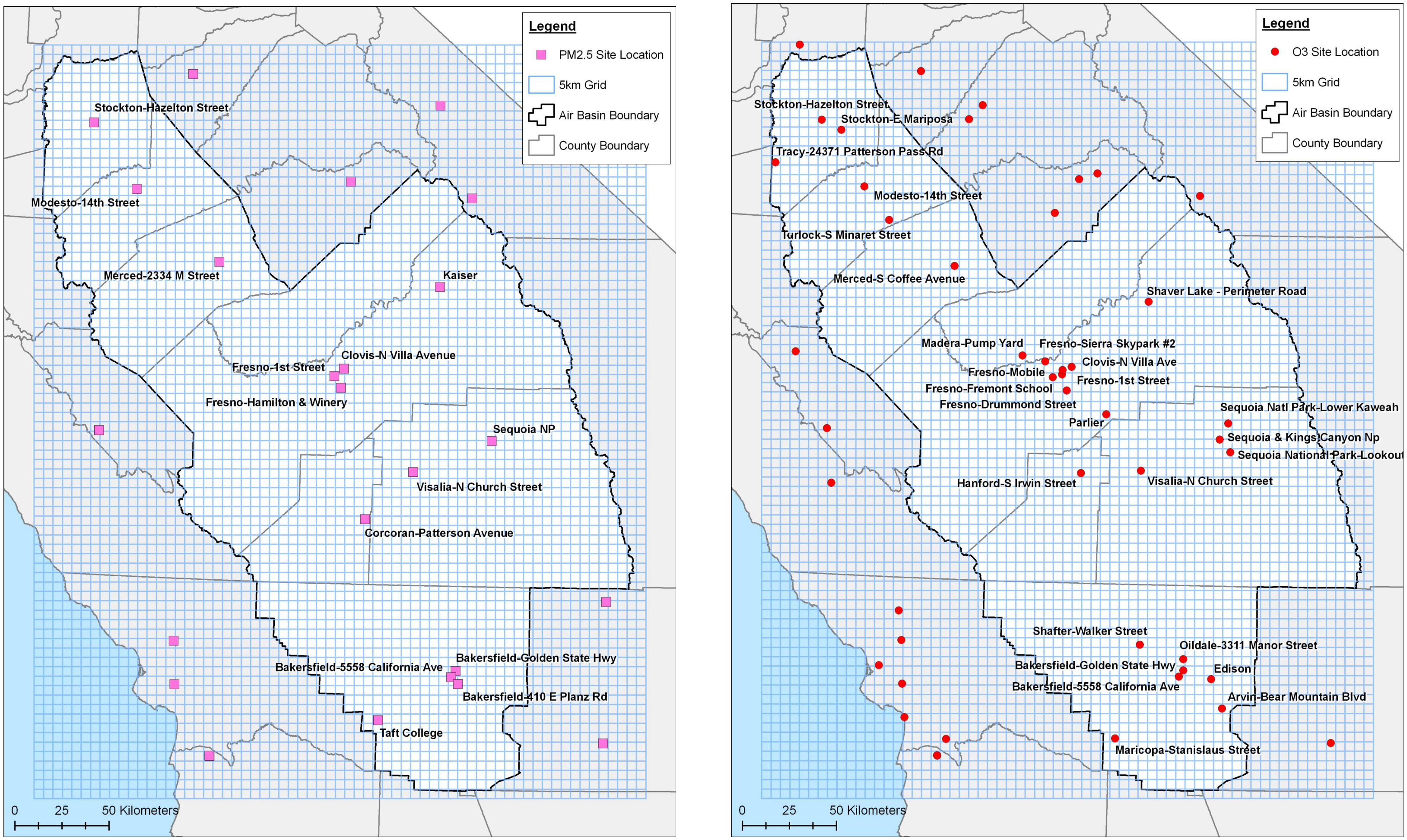


Figure III-5. Locations of air monitoring stations for $PM_{2.5}$ (left) and ozone (right) in and around the SJVAB

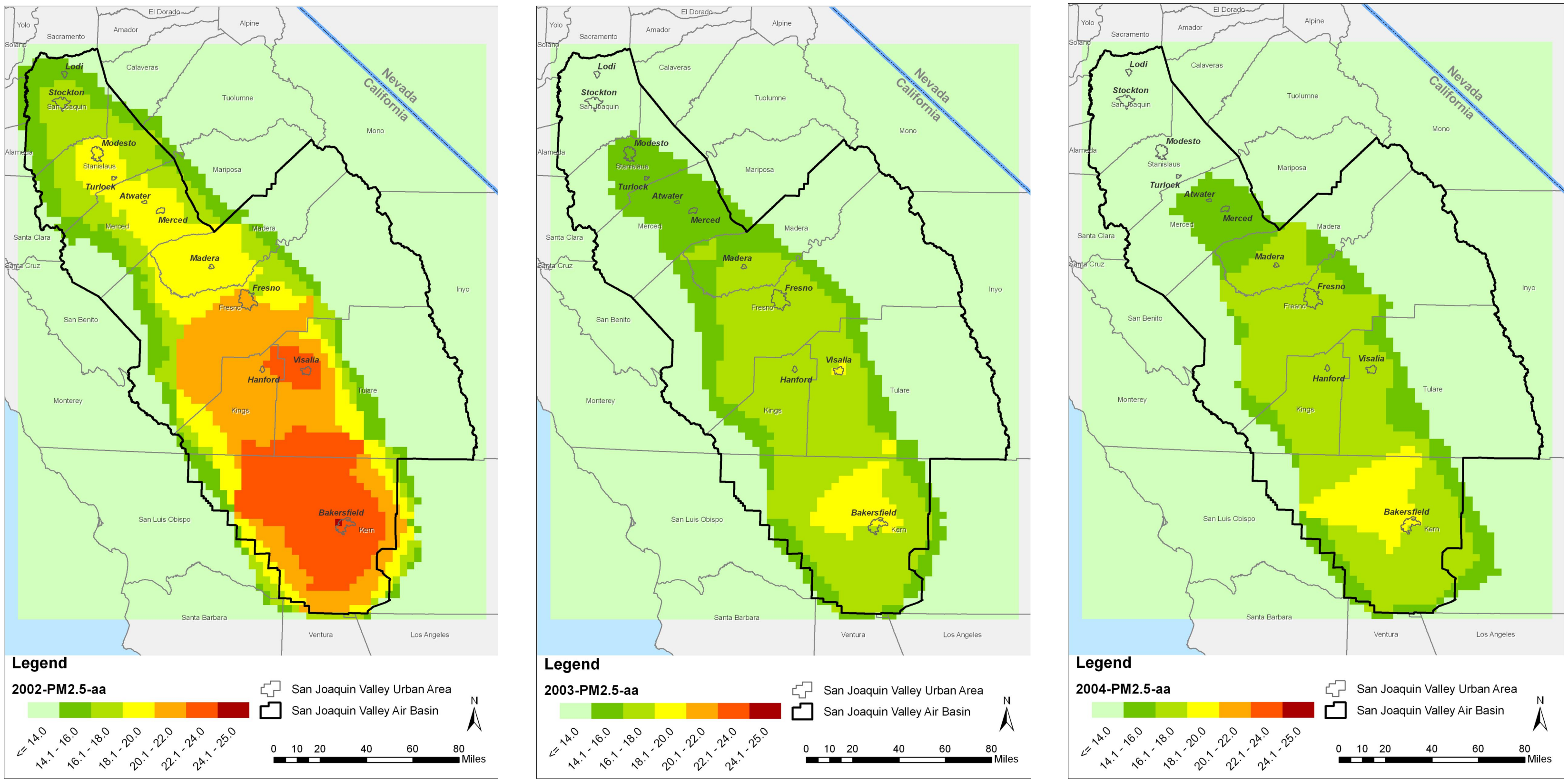


Figure III-6. Spatially mapped annual average $PM_{2.5}$ concentrations for 2002, 2003, and 2004 in the SJVAB.

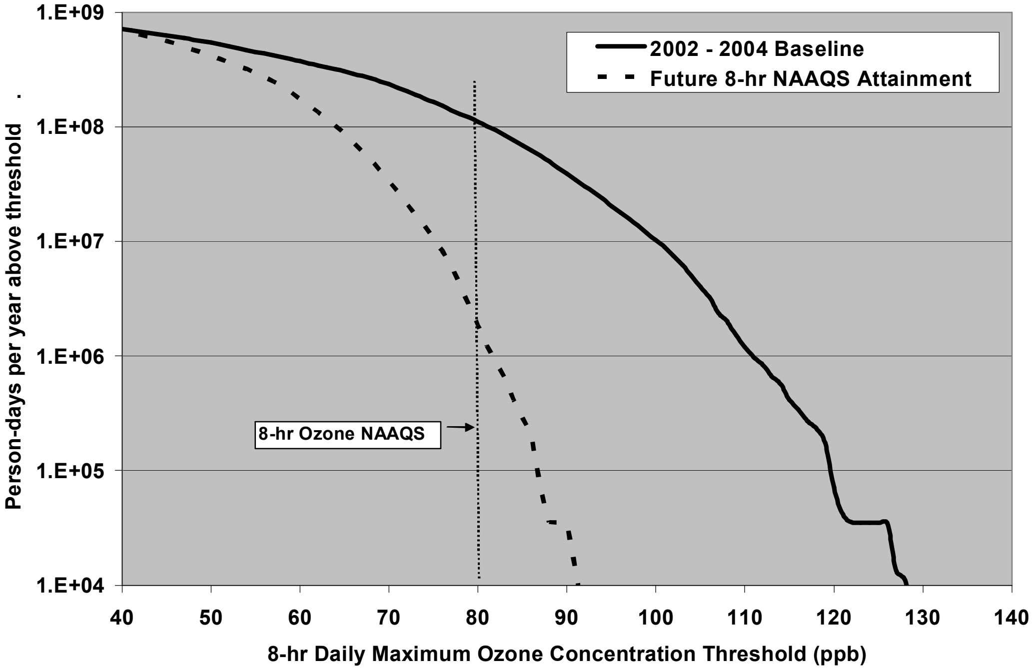


Figure III-7. The distribution of persons-days per year of exposure to 8-hour daily maximum ozone concentrations above various concentration thresholds in 2002-2004 and with NAAQS attainment.

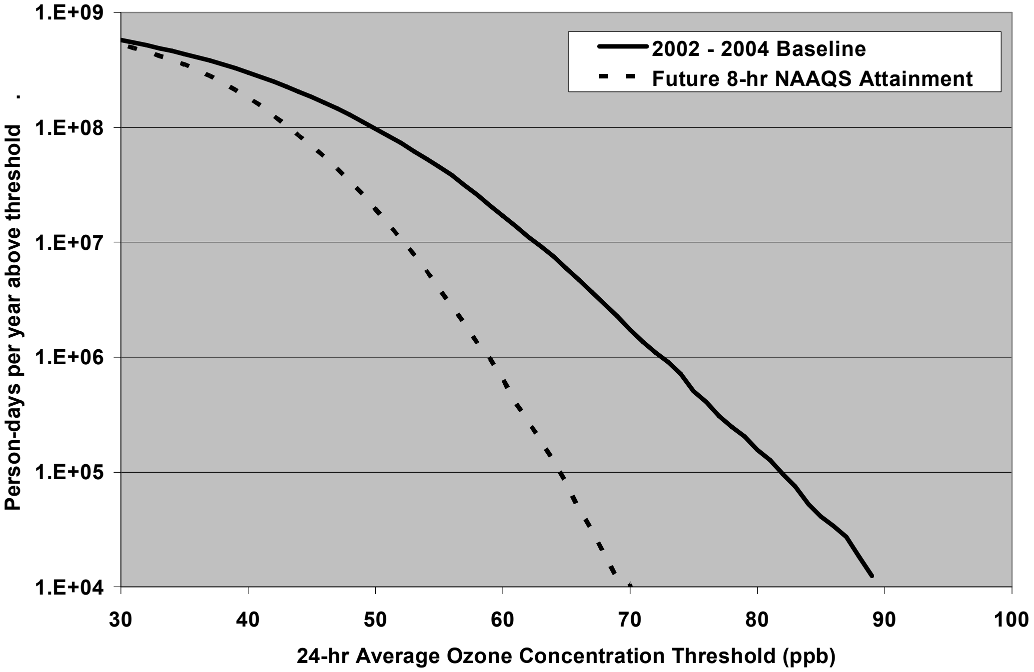


Figure III-8. The distribution of persons-days per year of exposure to 24-hour average ozone concentrations above various concentration thresholds in 2002-2004 and with NAAQS attainment.

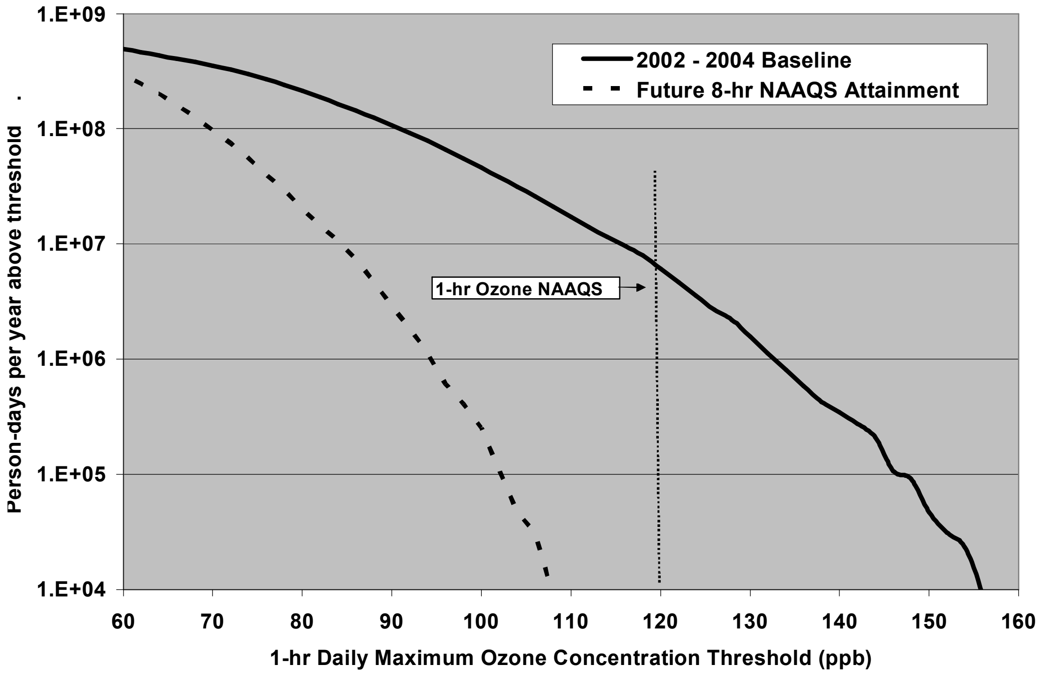


Figure III-9. The distribution of persons-days per year of exposure to 1-hour daily maximum ozone concentrations above various concentration thresholds in 2002-2004 and with NAAQS attainment.

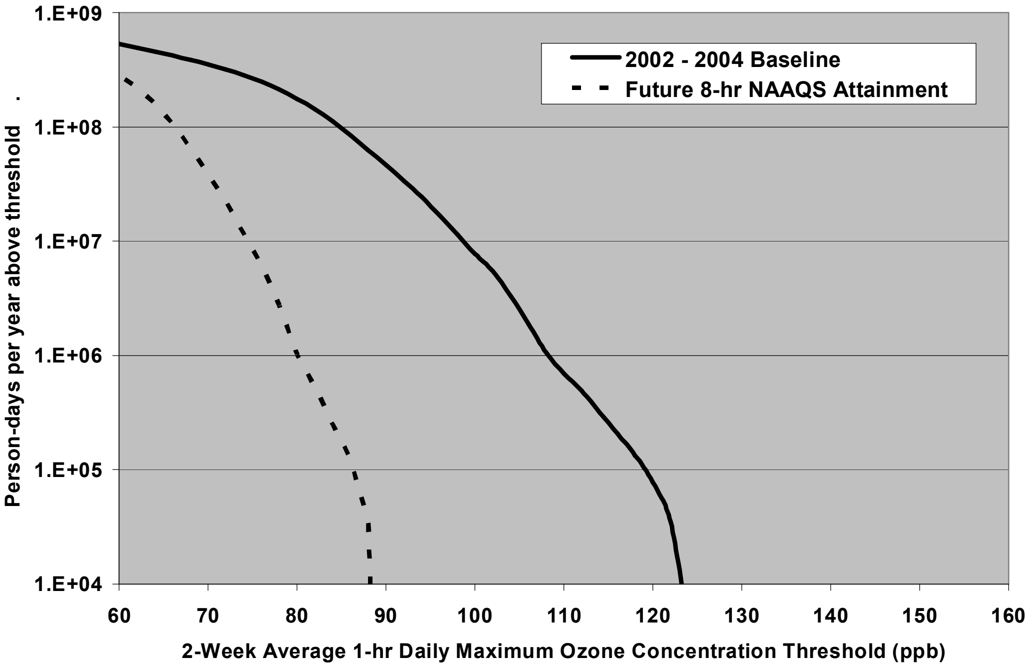


Figure III-10. The distribution of persons-days per year of exposure to 2-week average 1-hour daily maximum ozone concentrations above various concentration thresholds in 2002-2004 and with NAAQS attainment.

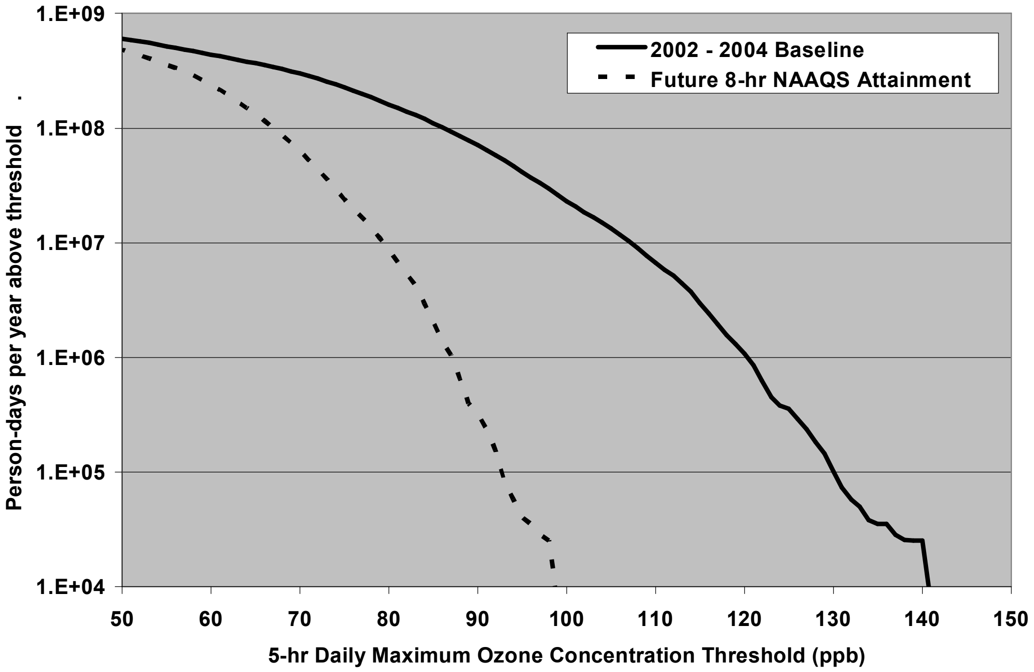


Figure III-11. The distribution of persons-days per year of exposure to 5-hour daily maximum ozone concentrations above various concentration thresholds in 2002-2004 and with NAAQS attainment.

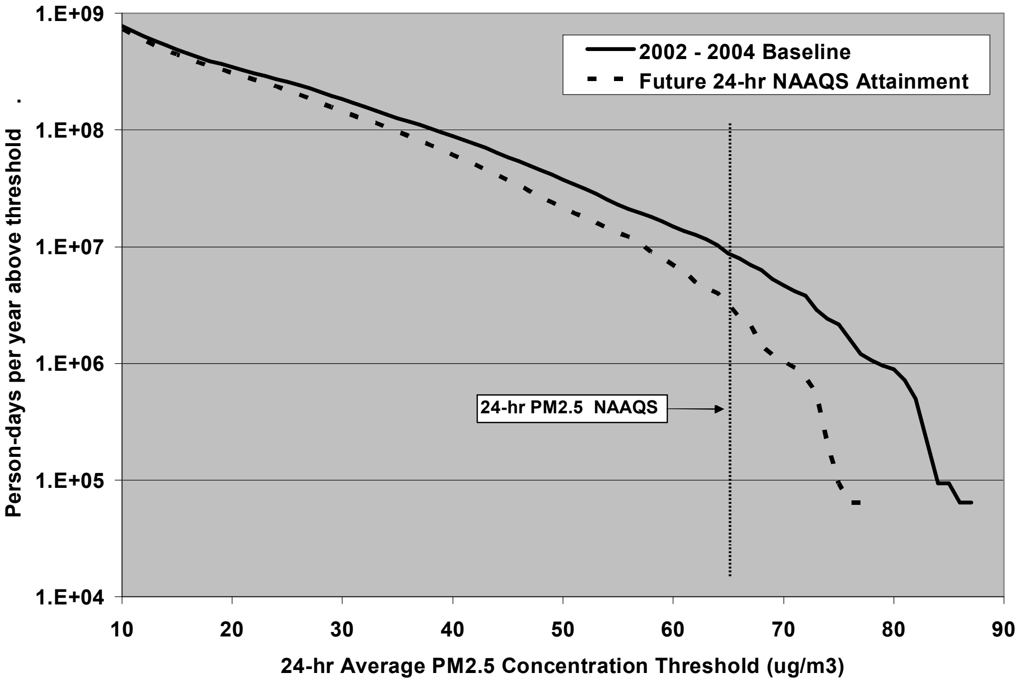


Figure III-12. The distribution of persons-days per year of exposure to 24-hour average $PM_{2.5}$ concentrations above various concentration thresholds in 2002-2004 and with NAAQS attainment.

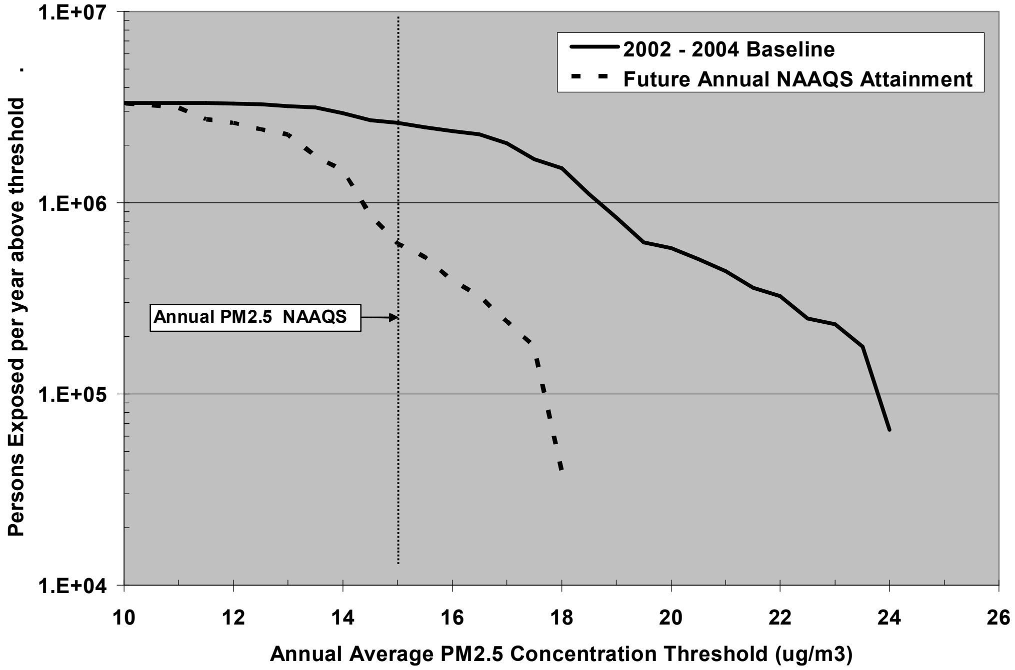


Figure III-13. The distribution of persons exposed per year to annual average $PM_{2.5}$ concentrations above various concentration thresholds in 2002-2004 and with the annual NAAQS attainment.

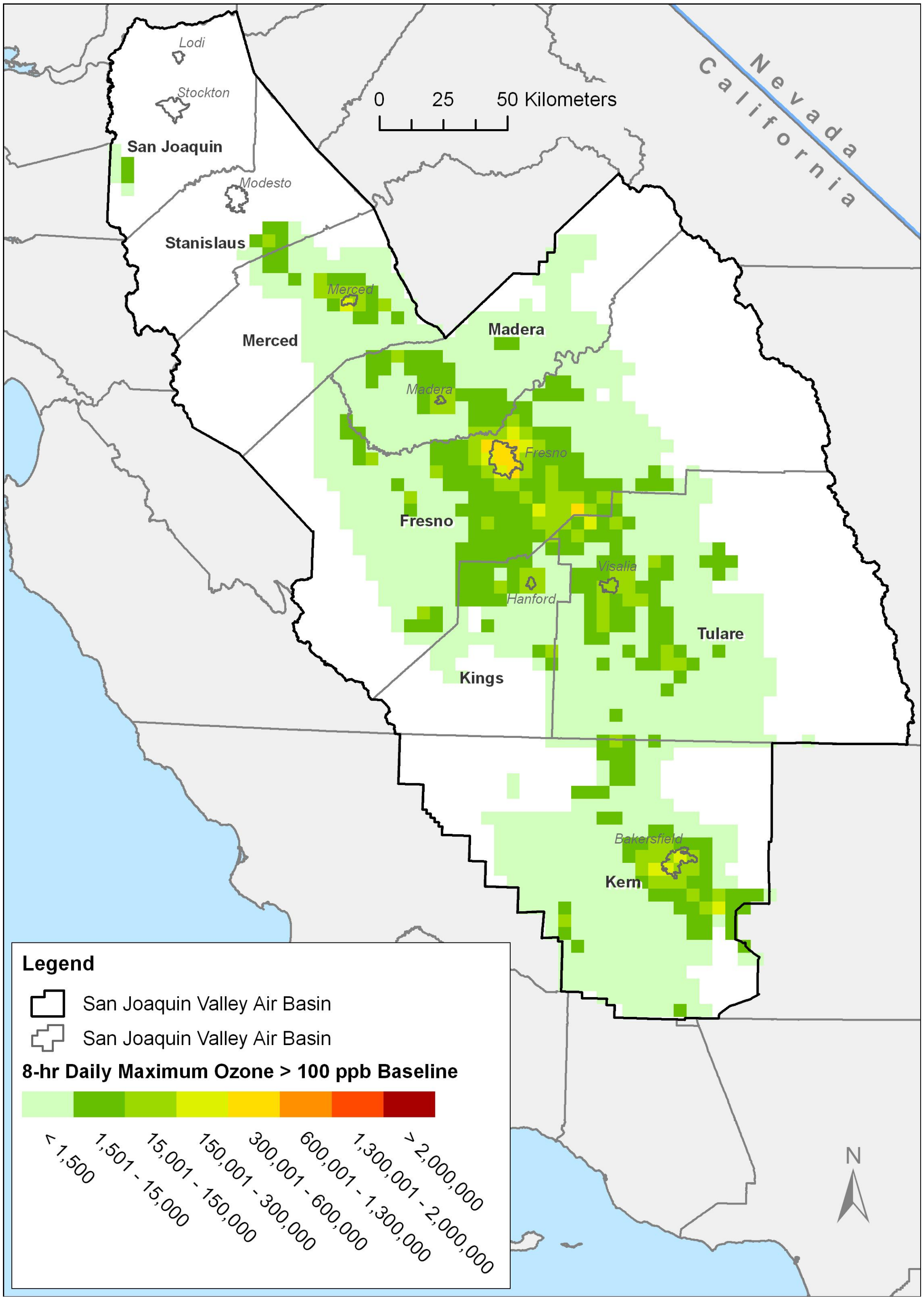


Figure III-14. Spatial map of the number of person-days per year of exposure to 8-hour daily maximum ozone concentrations above 100 ppb in 2002-2004.

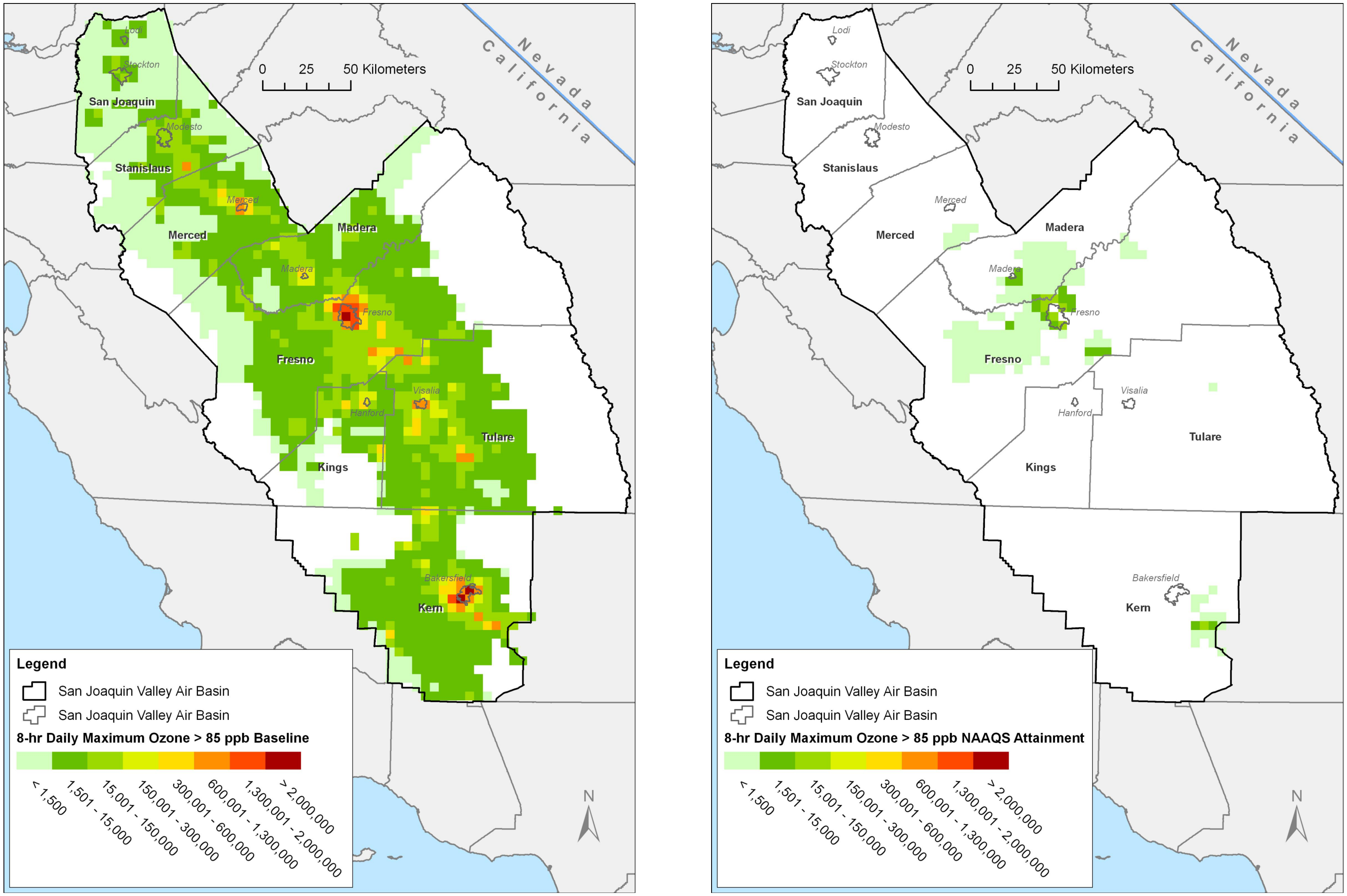


Figure III-15. Spatial map of the number of person-days per year of exposure to 8-hour daily maximum ozone concentrations above 85 ppb in 2002-2004 (left) and with NAAQS attainment (right).

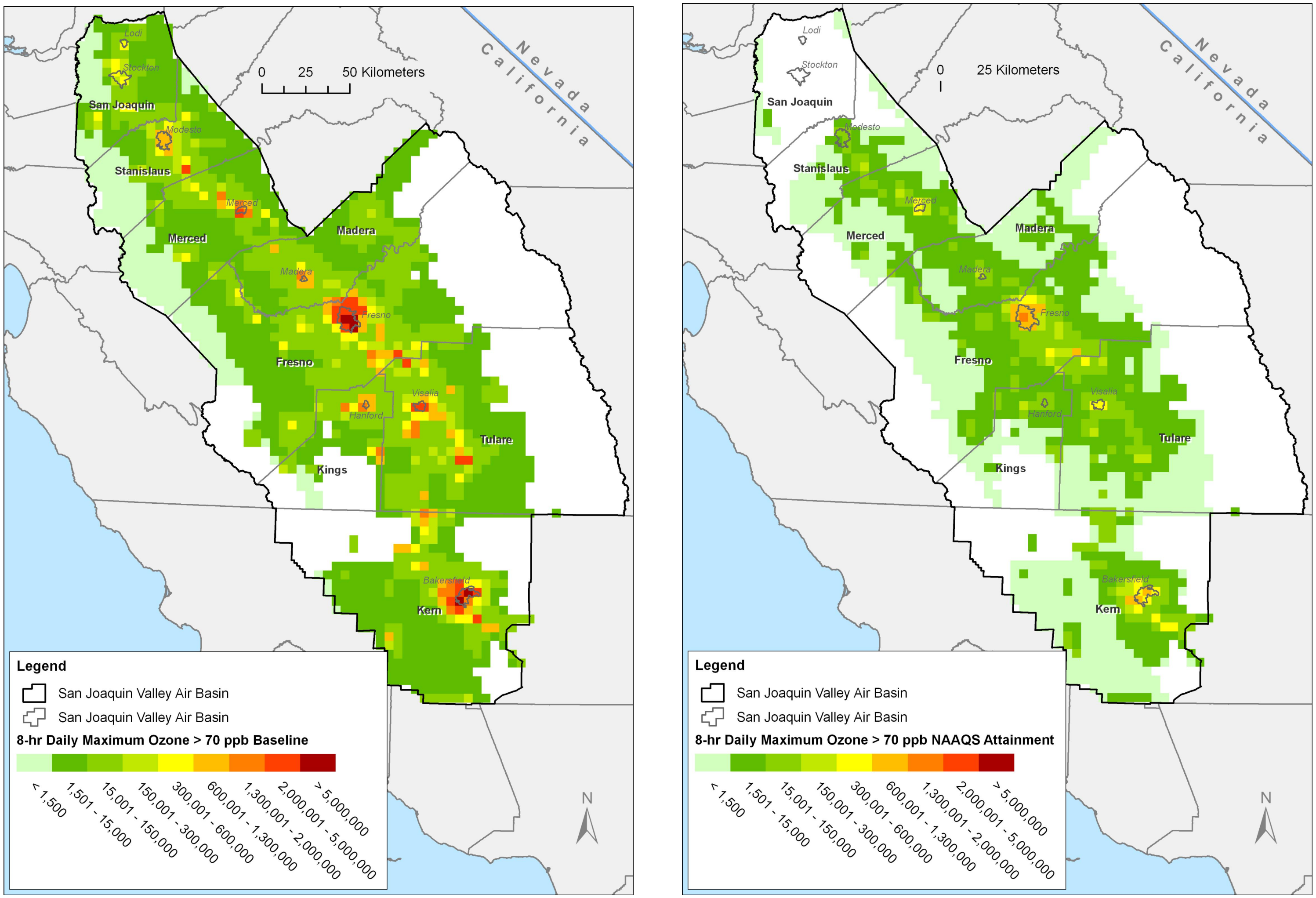


Figure III-16. Spatial map of the number of person-days per year of exposure to 8-hour daily maximum ozone concentrations above 70 ppb in 2002-2004 (left) and with NAAQS attainment (right).

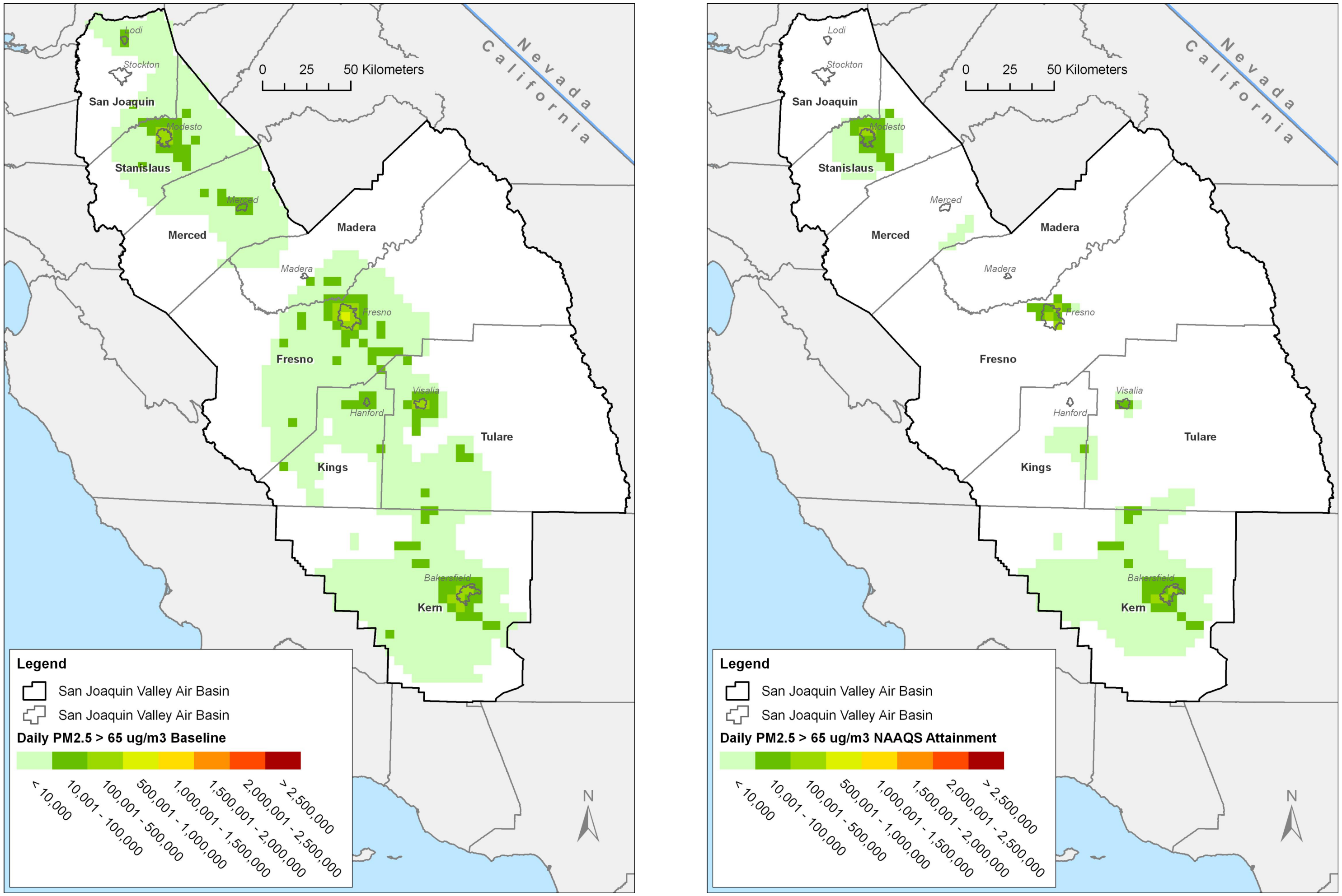


Figure III-17. Spatial map of the number of person-days per year of exposure to 24-hour average $PM_{2.5}$ concentrations above 65 $\mu g/m^3$ in 2002-2004 (left) and with 24-hour NAAQS attainment (right).

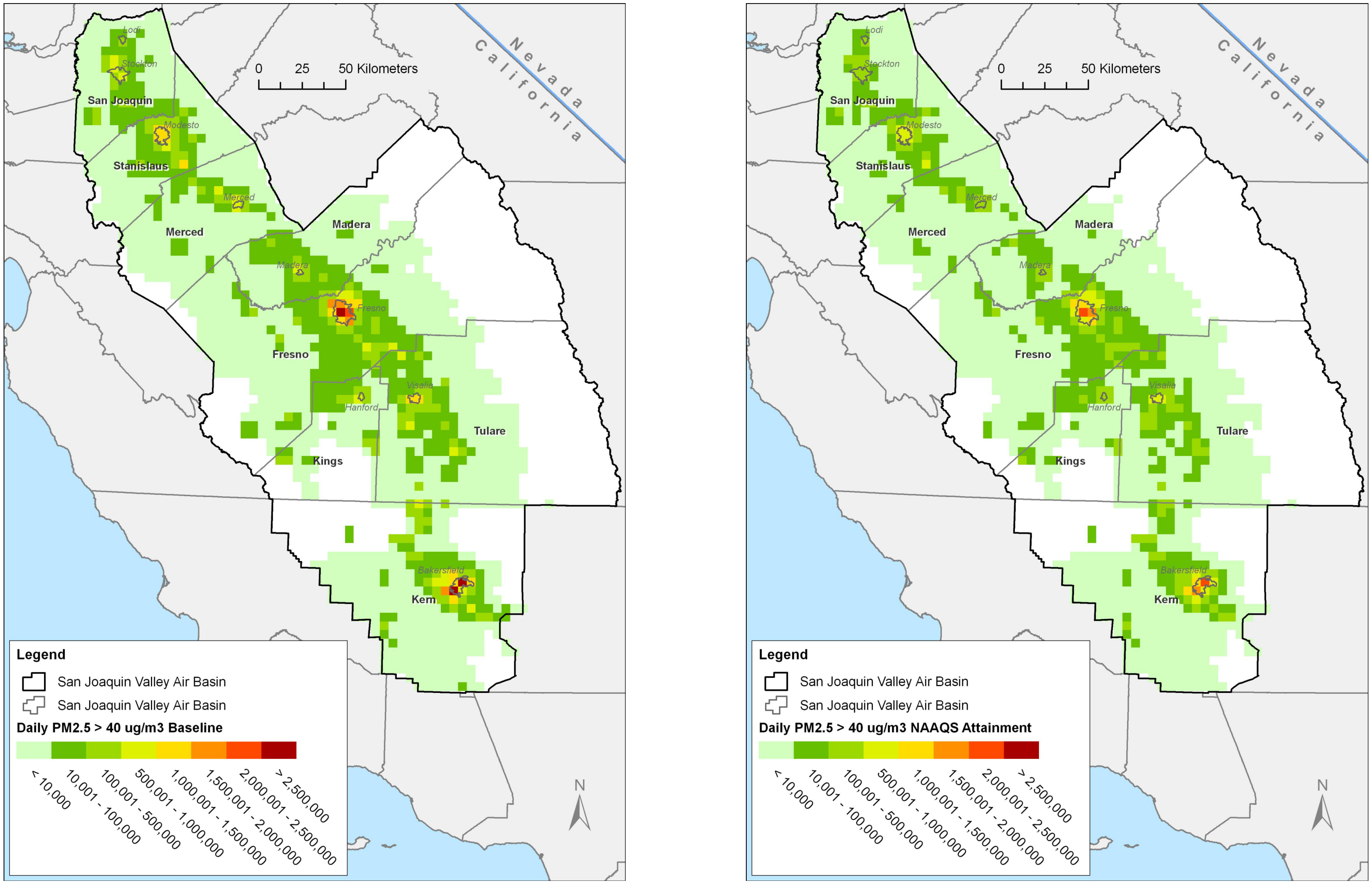


Figure III-18. Spatial map of the number of person-days per year of exposure to 24-hour average $PM_{2.5}$ concentrations above 40 $\mu g/m^3$ in 2002-2004 (left) and with 24-hour NAAQS attainment (right).

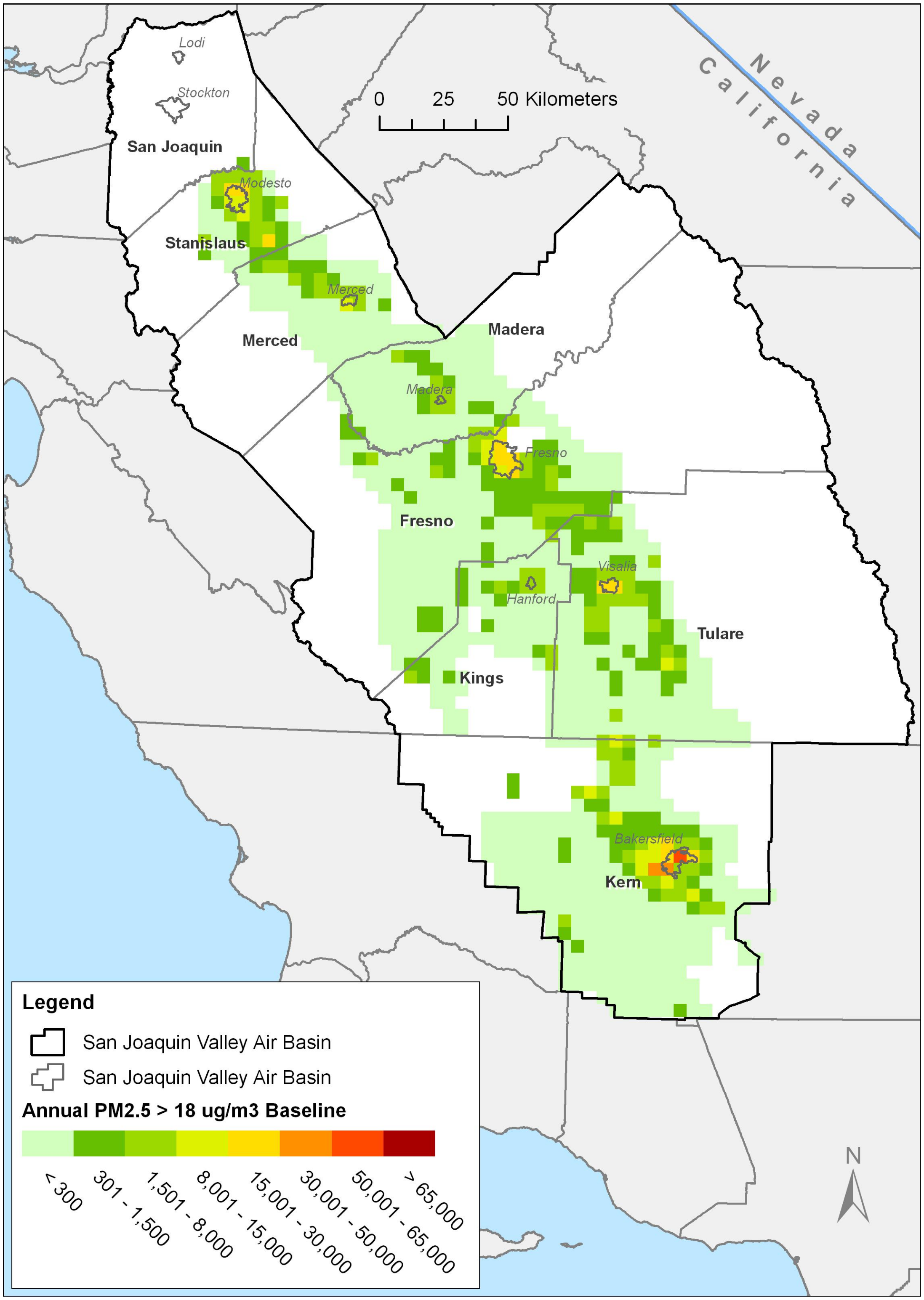


Figure III-19. Spatial map of the number of persons exposed (per year) to annual average PM$_{2.5}$ concentrations above 18 $\mu g/m^3$ in 2002-2004.

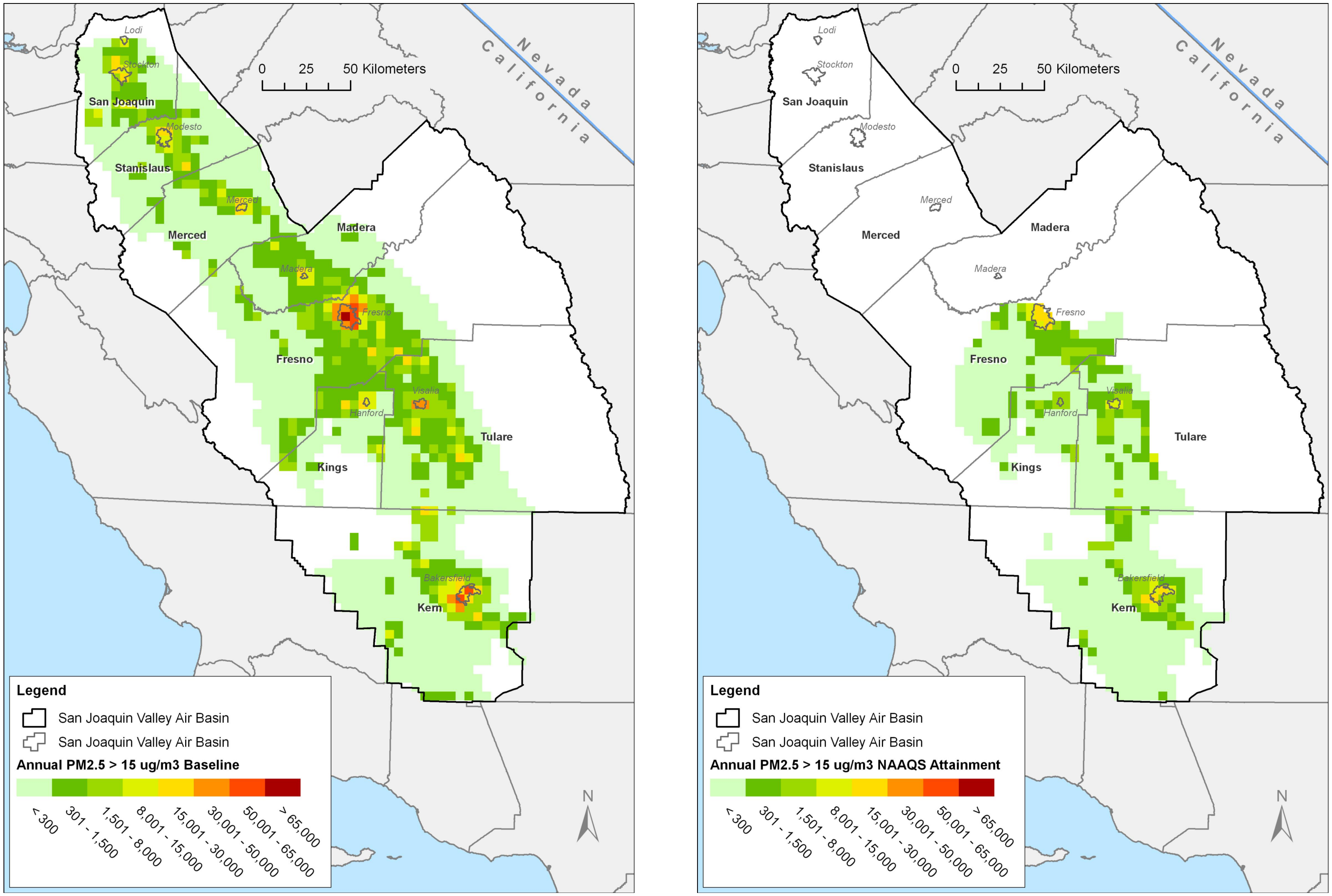


Figure III-20. Spatial map of the number of persons exposed to annual average PM$_{2.5}$ concentrations above 15 μg/m^3 in 2002-2004 (left) and with attainment (right).

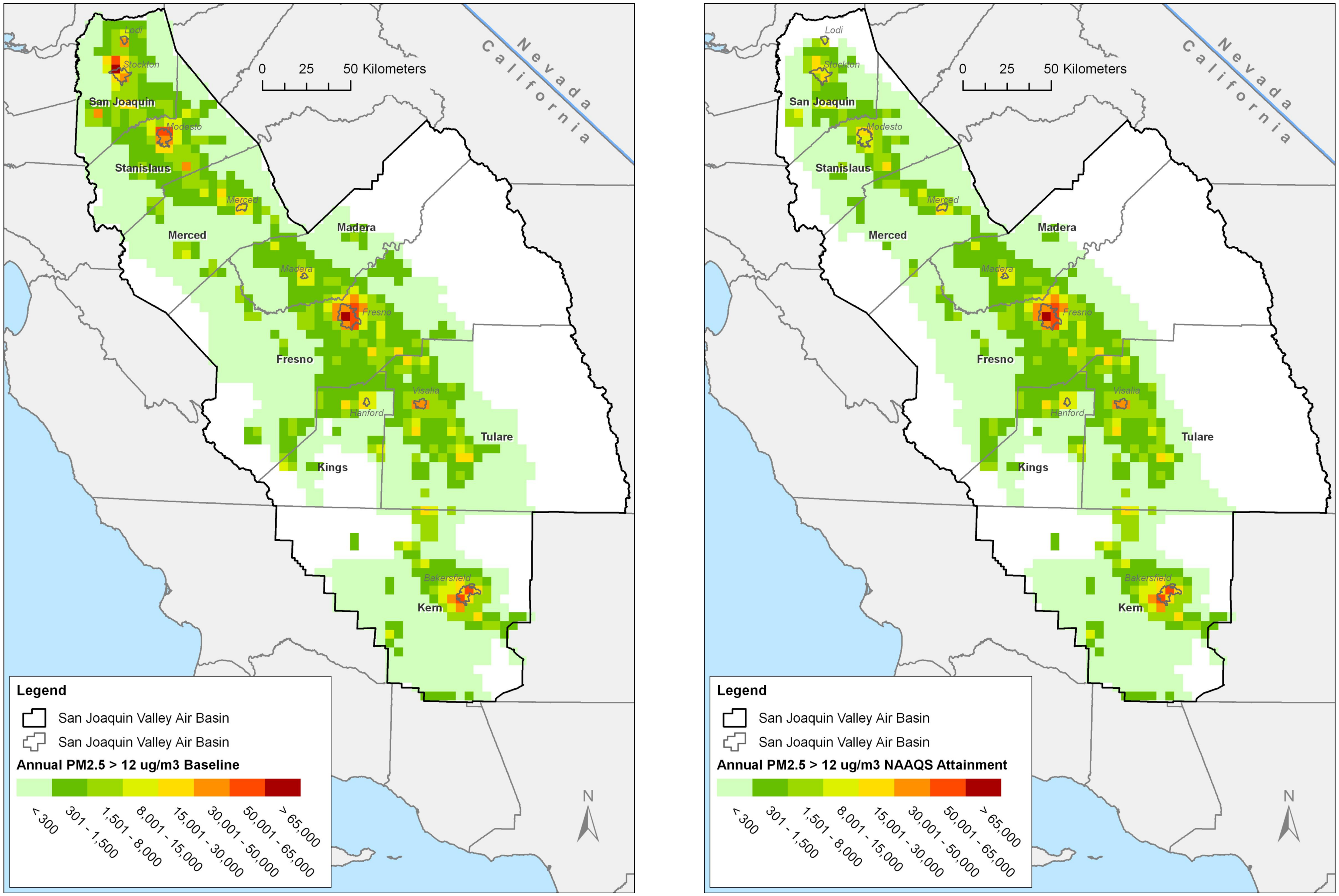


Figure III-21. Spatial map of the number of persons exposed to annual average $PM_{2.5}$ concentrations above 12 $\mu g/m^3$ in 2002-2004 (left) and with attainment (right).

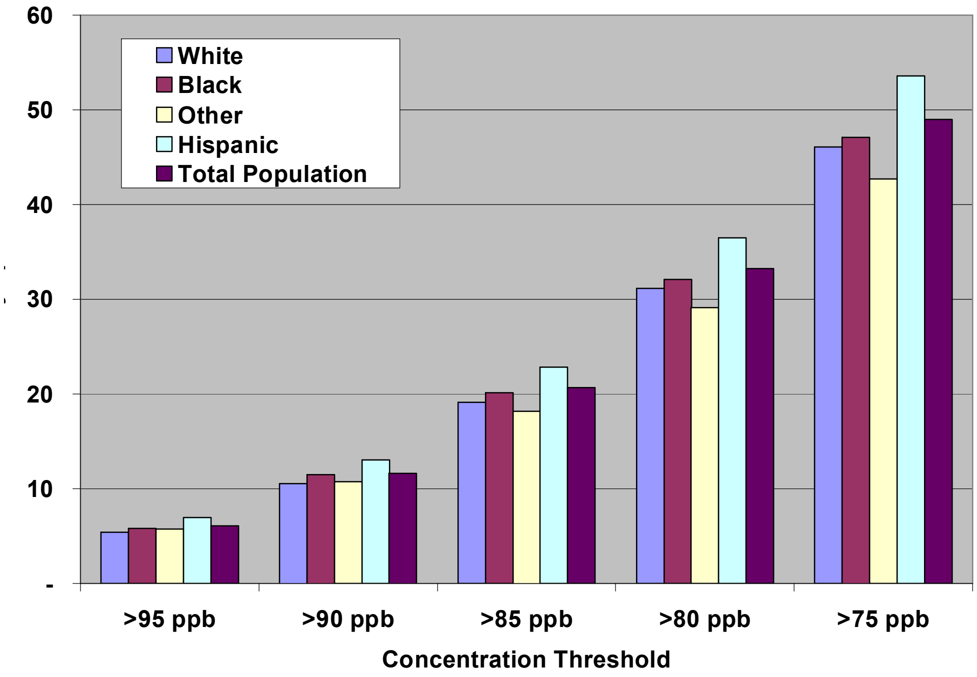


Figure III-22. The average number of days per year of exposure to 8-hour daily maximum ozone above various concentrations in the SJVAB in 2002-2004 by racial/ethnic group and county.

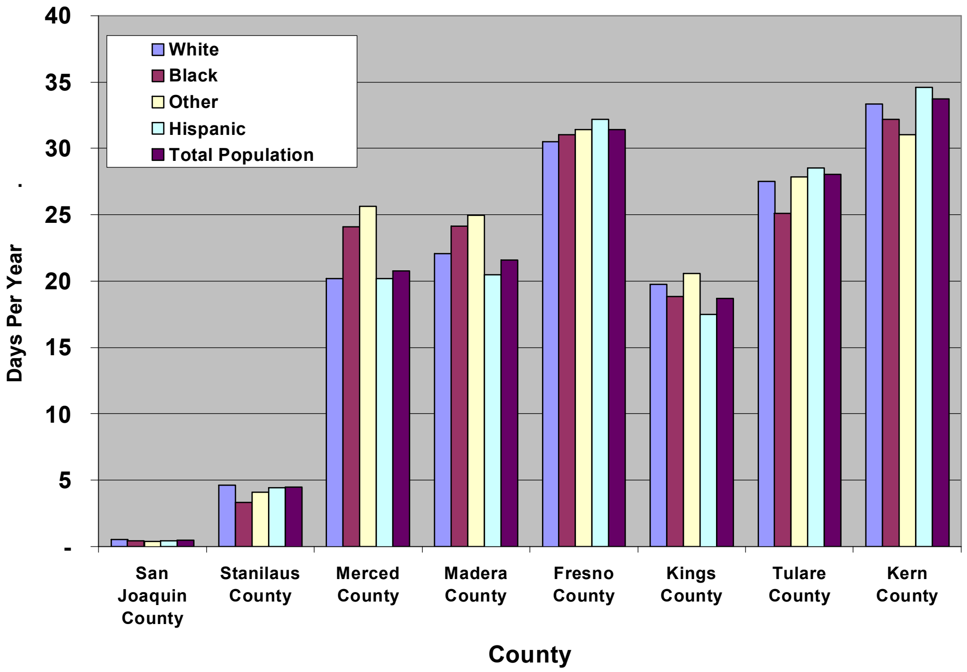


Figure III-23. The average number of days per year of exposure to 8-hour daily maximum ozone above 85 ppb in the SJVAB in 2002-2004 by racial/ethnic group and county.

Table III-10. The estimated SJVAB population exposure to 5-hour daily maximum ozone concentrations above 80, 90 and 100 ppb in the 2002-2004 baseline period and with NAAQS attainment by region.

Region	Person-days of Exposure Per Year in the 2002 – 2004 Baseline Period			Person-days of Exposure Per Year With NAAQS Attainment[a]	
	O_3 >80 ppb	O_3 >90 ppb	O_3 >100 ppb	O_3 >80 ppb	O_3 >90 ppb
SJV Air Basin	160,612,236	70,992,203	23,036,909	8,774,819	323,671
San Joaquin County	3,485,314	507,787	5,099	4,796	184
Stanislaus County	9,227,736	3,122,399	546,788	87,867	0
Merced County	10,013,959	4,521,107	1,445,128	255,225	0
Madera County	8,425,272	3,299,209	1,177,622	447,320	51,767
Fresno County	53,782,698	27,837,387	11,595,938	5,618,393	228,973
Kings County	6,594,764	2,795,412	792,613	259,751	0
Tulare County	27,267,903	11,699,739	3,085,285	1,027,820	6,769
Kern County	41,814,589	17,209,163	4,388,438	1,073,646	35,978

[a] SJVAB population exposure to 5-hour daily maximum ozone >100 ppb is estimated to be 6,770 person-days per year with attainment of the 8-hour NAAQS.

Table III-11. The estimated SJVAB population exposure to 1-hour daily maximum ozone concentrations above 80, 100, and 120 ppb in the 2002-2004 baseline period and with NAAQS attainment by region.

Region	Person-days of Exposure Per Year in the 2002 – 2004 Baseline Period			Person-days of Exposure Per Year With NAAQS Attainment[a]	
	O_3 >80 ppb	O_3 >100 ppb	O_3 >120 ppb	O_3 >80 ppb	O_3 >100 ppb
SJV Air Basin	213,217,847	45,904,168	6,063,003	20,176,110	254,935
San Joaquin County	8,395,004	488,874	4,888	10,681	4,728
Stanislaus County	15,166,787	2,353,467	48,987	534,337	0
Merced County	13,345,890	2,755,607	90,682	1,052,372	105
Madera County	10,842,116	2,088,746	293,815	1,008,657	34,359
Fresno County	69,222,219	20,903,413	4,408,225	11,620,506	185,340
Kings County	9,113,833	1,692,956	179,469	664,759	0
Tulare County	34,870,509	7,110,469	576,116	2,853,119	7,173
Kern County	52,261,490	8,510,636	460,819	2,431,680	23,230

[a] SJVAB population exposure to 1-hour daily maximum ozone >120 ppb is estimated to be zero with attainment of the 8-hour NAAQS.

Table III-12. The estimated SJVAB population exposure to 2-week average 1-hour daily maximum ozone concentrations above 80, 100, and 120 ppb in the 2002-2004 baseline period and with NAAQS attainment by region.

Region	Person-days of Exposure Per Year in the 2002 – 2004 Baseline Period			With NAAQS Attainment[a]
	O_3 >80 ppb	O_3 >100 ppb	O_3 >120 ppb	O_3 >80 ppb
SJV Air Basin	176,546,856	7,754,966	77,308	1,020,681
San Joaquin County	29,539	0	0	0
Stanislaus County	3,631,794	0	0	0
Merced County	10,437,480	148,280	0	0
Madera County	9,299,083	206,757	0	41,004
Fresno County	68,672,341	4,893,914	31,738	497,532
Kings County	6,769,397	48,949	0	126
Tulare County	33,531,673	1,056,492	403	110,562
Kern County	44,175,548	1,400,575	45,166	371,457

[a] SJVAB population exposure to 2-week average 1-hour daily maximum ozone >100 ppb is estimated to be zero with attainment of the 8-hour NAAQS.

Table III-13. The estimated SJVAB population exposure to 24-hour average ozone concentrations above 50, 60, and 70 ppb in the 2002-2004 baseline period and with NAAQS attainment by region.

Region	Person-days of Exposure Per Year in the 2002 – 2004 Baseline Period			Person-days of Exposure Per Year With NAAQS Attainment[a]	
	O_3 >50 ppb	O_3 >60 ppb	O_3 >70 ppb	O_3 >50 ppb	O_3 >60 ppb
SJV Air Basin	97,277,322	16,992,036	1,741,620	19,462,969	653,916
San Joaquin County	319,971	787	0	6,418	0
Stanislaus County	1,867,299	44,491	79	59,409	0
Merced County	8,842,703	1,719,219	193,478	1,908,731	30,960
Madera County	7,058,729	1,478,549	137,148	1,790,058	23,539
Fresno County	35,382,682	4,695,127	76,214	4,426,329	14,643
Kings County	3,023,231	110,651	0	112,848	0
Tulare County	18,298,749	4,094,132	502,563	5,376,160	197,971
Kern County	22,483,957	4,849,080	832,139	5,783,017	386,803

[a] SJVAB population exposure to 24-hour average ozone >70 ppb is estimated to be 32,000 person-days per year with attainment of the 8-hour NAAQS.

Table III-14. The estimated SJVAB population exposure to 24-hour average $PM_{2.5}$ concentrations above 40 and 65 µg/m^3 in the 2002-2004 baseline period and with NAAQS attainment by region.

Region	Person-days of Exposure Per Year in the 2002 – 2004 Baseline Period		Person-days of Exposure Per Year With NAAQS Attainment	
	$PM_{2.5}$ >40 µg/m^3	$PM_{2.5}$ >65 µg/m^3	$PM_{2.5}$ >40 µg/m^3	$PM_{2.5}$ >65 µg/m^3
SJV Air Basin	88,444,759	8,740,819	61,210,349	3,244,681
San Joaquin County	6,952,506	179,520	3,128,221	6,152
Stanislaus County	10,598,815	1,319,551	6,330,681	816,627
Merced County	4,517,016	337,293	2,602,691	1,509
Madera County	4,176,348	159,435	2,512,053	0
Fresno County	25,612,174	3,536,683	19,033,269	961,833
Kings County	3,704,890	415,924	2,909,207	27,889
Tulare County	9,857,985	724,773	7,308,016	102,482
Kern County	23,025,025	2,067,641	17,386,210	1,328,188

Table III-15. The estimated average number of days per year that the SJVAB population is exposed to 24-hour $PM_{2.5}$ concentrations above 40 and 65 µg/m^3 in the 2002-2004 baseline period and with NAAQS attainment by region.

Region	Average No. of Days of Exposure Per Year in the 2002 – 2004 Baseline Period		Average No. of Days of Exposure Per Year With NAAQS Attainment	
	$PM_{2.5}$ >40 µg/m^3	$PM_{2.5}$ >65 µg/m^3	$PM_{2.5}$ >40 µg/m^3	$PM_{2.5}$ >65 µg/m^3
SJV Air Basin	26	3	18	1
San Joaquin County	12	0	5	<1
Stanislaus County	23	3	14	2
Merced County	20	2	12	<1
Madera County	26	1	16	0
Fresno County	32	4	23	1
Kings County	27	3	21	<1
Tulare County	26	2	19	<1
Kern County	39	4	30	2

Table III-16. The estimated SJVAB population exposure to 24-hour average $PM_{2.5}$ concentrations above 40 and 65 µg/m^3 in the 2002-2004 baseline period and with NAAQS attainment by age group.

Age Group	Person-days of Exposure Per Year in the 2002 – 2004 Baseline Period		Person-days of Exposure Per Year With NAAQS Attainment	
	$PM_{2.5}$ >40 µg/m^3	$PM_{2.5}$ >65 µg/m^3	$PM_{2.5}$ >40 µg/m^3	$PM_{2.5}$ >65 µg/m^3
Children <1 Year	1,451,170	145,336	1,014,127	53,513
Children 1 Year	1,469,069	146,894	1,024,404	54,377
Children 2-4 Years	4,573,955	457,019	3,184,968	168,053
Children 5-17 Years	20,902,138	2,073,829	14,525,114	761,301
Adults 18-21 Years	5,634,636	556,778	3,910,283	206,015
Adults 22-29 Years	10,110,743	1,002,256	7,031,299	373,369
Adults 30-64 Years	35,816,787	3,503,922	24,685,357	1,313,479
Adults >64 Years	8,486,261	854,785	5,834,797	314,575

Table III-17. The estimated SJVAB population exposure to 24-hour average $PM_{2.5}$ concentrations above 40 and 65 µg/m^3 in the 2002-2004 baseline period and with NAAQS attainment by racial or ethnic group.

Group	Person-days of Exposure Per Year in the 2002 – 2004 Baseline Period		Person-days of Exposure Per Year With NAAQS Attainment	
	$PM_{2.5}$ >40 µg/m^3	$PM_{2.5}$ >65 µg/m^3	$PM_{2.5}$ >40 µg/m^3	$PM_{2.5}$ >65 µg/m^3
White	39,421,625	3,842,572	26,815,582	1,558,292
Black	4,439,192	486,888	3,128,836	163,693
Other	38,467,115	3,771,060	27,133,707	1,300,489
Hispanic	6,158,795	643,435	4,160,633	223,028

Table III-18. The estimated average number of days per year that the SJVAB population is exposed to 24-hour $PM_{2.5}$ concentrations above 40 and 65 µg/m^3 in the 2002-2004 baseline period and with NAAQS attainment by racial or ethnic group.

Group	Average No. of Days of Exposure Per Year in the 2002 – 2004 Baseline Period		Average No. of Days of Exposure Per Year With NAAQS Attainment[a]	
	$PM_{2.5}$ >40 µg/m^3	$PM_{2.5}$ >65 µg/m^3	$PM_{2.5}$ >40 µg/m^3	$PM_{2.5}$ >65 µg/m^3
White	26	2	17	1
Black	28	3	20	1
Hispanic	28	3	19	1
Other	25	3	17	1

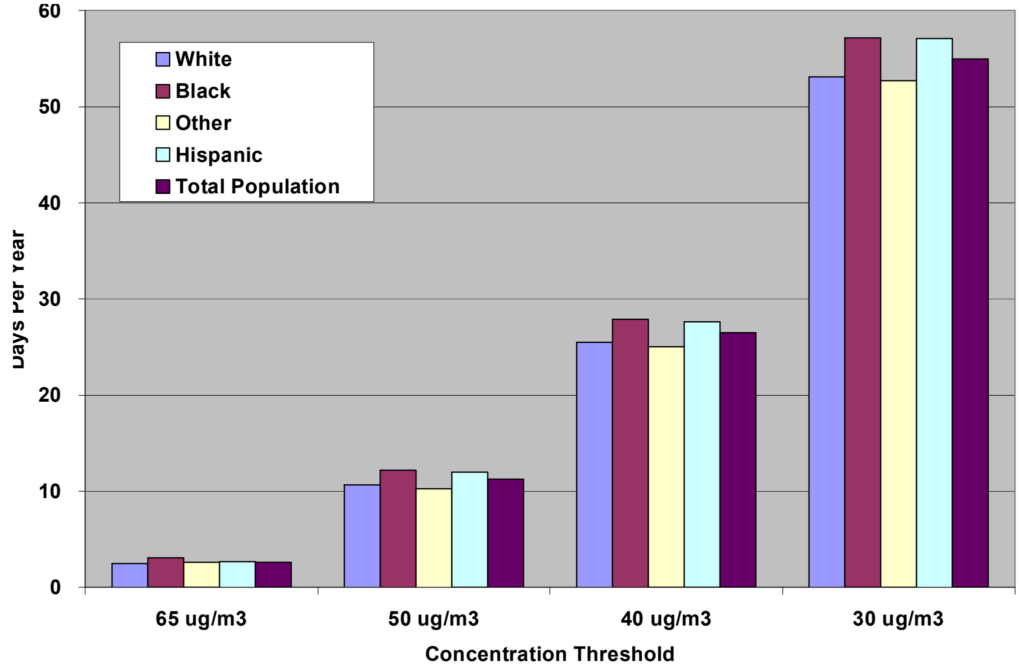


Figure III-24. The average number of days per year of exposure to 24-hour average $PM_{2.5}$ above various concentrations in the SJVAB in 2002-2004 by racial/ethnic group.

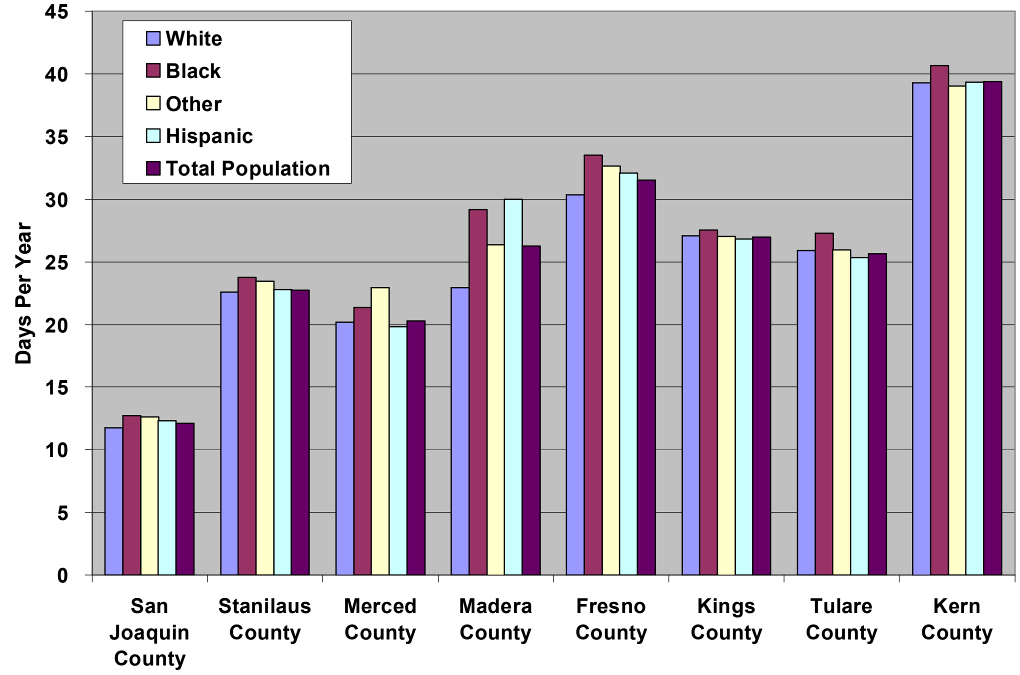


Figure III-25. The average number of days per year of exposure to 24-hour average $PM_{2.5}$ above 40 $\mu g/m^3$ in the SJVAB in 2002-2004 by racial/ethnic group and county.

Table III-19. The estimated SJVAB population exposure to annual average $PM_{2.5}$ concentrations above 12, 15, and 18 µg/m^3 in the 2002-2004 baseline period and with NAAQS attainment by region.

Region	Person-days of Exposure Per Year in the 2002 – 2004 Baseline Period			Person-days of Exposure Per Year With NAAQS Attainment[a]	
	$PM_{2.5}$ >12 µg/m^3	$PM_{2.5}$ >15 µg/m^3	$PM_{2.5}$ >18 µg/m^3	$PM_{2.5}$ >12 µg/m^3	$PM_{2.5}$ >15 µg/m^3
SJV Air Basin	3,266,891	2,485,816	1,110,165	2,429,546	520,575
San Joaquin County	548,259	180,226	733	179,474	0
Stanislaus County	465,500	155,140	140,181	155,101	0
Merced County	209,607	148,200	55,780	107,450	0
Madera County	139,758	135,335	44,189	134,303	0
Fresno County	802,163	784,847	214,722	783,162	182,782
Kings County	137,234	134,433	45,745	130,317	41,082
Tulare County	380,256	363,833	156,907	356,090	102,345
Kern County	584,114	583,802	451,908	583,649	194,366

[a] None of the SJVAB population is estimated to be exposed to annual average $PM_{2.5}$ concentrations above >18 µg/m^3 with attainment of the annual $PM_{2.5}$ NAAQS.

Table III-20. The estimated percent of the SJVAB population exposed to annual average $PM_{2.5}$ concentrations above 12, 15, and 18 µg/m^3 in the 2002-2004 baseline period and with NAAQS attainment by region.

Region	Percent of the Population Exposed in the 2002 – 2004 Baseline Period			Percent of the Population Exposed With NAAQS Attainment[a]	
	$PM_{2.5}$ >12 µg/m^3	$PM_{2.5}$ >15 µg/m^3	$PM_{2.5}$ >18 µg/m^3	$PM_{2.5}$ >12 µg/m^3	$PM_{2.5}$ >15 µg/m^3
SJV Air Basin	98%	74%	33%	73%	16%
San Joaquin County	96%	31%	0%	31%	0%
Stanislaus County	100%	33%	30%	33%	0%
Merced County	94%	67%	25%	48%	0%
Madera County	88%	85%	28%	84%	0%
Fresno County	99%	97%	26%	96%	22%
Kings County	100%	98%	33%	95%	30%
Tulare County	99%	95%	41%	93%	27%
Kern County	98%	74%	33%	73%	16%

[a] None of the SJVAB population is estimated to be exposed to annual average $PM_{2.5}$ concentrations above >18 µg/m^3 with attainment of the annual $PM_{2.5}$ NAAQS.

Table III-21. The estimated SJVAB population exposure to annual average $PM_{2.5}$ concentrations above 12, 15, and 18 µg/m^3 in the 2002-2004 baseline period and with NAAQS attainment by age group.

Age Group	Person-days of Exposure Per Year in the 2002 – 2004 Baseline Period			Person-days of Exposure Per Year With NAAQS Attainment[a]	
	$PM_{2.5}$ >12 µg/m^3	$PM_{2.5}$ >15 µg/m^3	$PM_{2.5}$ >18 µg/m^3	$PM_{2.5}$ >12 µg/m^3	$PM_{2.5}$ >15 µg/m^3
Children <1 Year	52,518	40,905	18,534	40,018	8,969
Children 1 Year	53,244	41,327	18,703	40,421	8,959
Children 2-4 Years	166,507	128,722	58,015	125,823	27,787
Children 5-17 Years	767,767	588,313	264,331	574,640	125,186
Adults 18-21 Years	206,777	159,584	70,214	155,994	33,718
Adults 22-29 Years	367,444	285,834	127,762	279,426	61,316
Adults 30-64 Years	1,332,637	1,005,231	448,785	982,455	205,947
Adults >64 Years	319,994	235,898	103,822	230,767	48,692

[a] Zero percent of the SJVAB population is estimated to be exposed to annual average $PM_{2.5}$ concentrations above >18 µg/m^3 with attainment of the annual $PM_{2.5}$ NAAQS.

Table III-22. The percent of the SJVAB population exposed to annual average $PM_{2.5}$ concentrations above 12, 15, and 18 µg/m^3 in the 2002-2004 baseline period and with NAAQS attainment by age group.

Age Group	Percent of the Population Exposed in the 2002 – 2004 Baseline Period			Percent of the Population Exposed With NAAQS Attainment[a]	
	$PM_{2.5}$ >12 µg/m^3	$PM_{2.5}$ >15 µg/m^3	$PM_{2.5}$ >18 µg/m^3	$PM_{2.5}$ >12 µg/m^3	$PM_{2.5}$ >15 µg/m^3
Children <1 Year	98%	77%	35%	75%	17%
Children 1 Year	98%	76%	35%	75%	17%
Children 2-4 Years	98%	76%	34%	74%	16%
Children 5-17 Years	98%	75%	34%	73%	16%
Adults 18-21 Years	98%	76%	33%	74%	16%
Adults 22-29 Years	98%	77%	34%	75%	16%
Adults 30-64 Years	98%	74%	33%	72%	15%
Adults >64 Years	97%	72%	32%	70%	15%

[a] Zero percent of the SJVAB population is estimated to be exposed to annual average $PM_{2.5}$ concentrations above >18 µg/m^3 with attainment of the annual $PM_{2.5}$ NAAQS.

Table III-23. The estimated SJVAB population exposure to annual average PM2.5 concentrations above 12, 15 and 18 µg/m3 in the 2002-2004 baseline period and with NAAQS attainment by racial or ethnic group.

Group	Person-days of Exposure Per Year in the 2002 – 2004 Baseline Period			Person-days of Exposure Per Year With NAAQS Attainment[a]	
	$PM_{2.5}$ >12 µg/m^3	$PM_{2.5}$ >15 µg/m^3	$PM_{2.5}$ >18 µg/m^3	$PM_{2.5}$ >12 µg/m^3	$PM_{2.5}$ >15 µg/m^3
White	1,495,318	1,085,149	496,585	1,062,947	208,770
Black	157,070	122,784	51,819	120,417	28,525
Hispanic	1,373,857	1,105,462	498,035	1,078,506	250,913
Other	242,304	173,721	64,248	168,918	32,672

[a] None of the SJVAB population is estimated to be exposed to annual average $PM_{2.5}$ concentrations above >18 µg/m^3 with attainment of the annual $PM_{2.5}$ NAAQS.

Table III-24. The estimated percent of the SJVAB population exposed to annual average $PM_{2.5}$ concentrations above 12, 15, and 18 µg/m^3 in the 2002-2004 baseline period and with NAAQS attainment by racial or ethnic group.

Group	Percent of the Population Exposed in the 2002 – 2004 Baseline Period			Percent of the Population Exposed With NAAQS Attainment[a]	
	$PM_{2.5}$ >12 µg/m^3	$PM_{2.5}$ >15 µg/m^3	$PM_{2.5}$ >18 µg/m^3	$PM_{2.5}$ >12 µg/m^3	$PM_{2.5}$ >15 µg/m^3
White	97%	70%	32%	69%	14%
Black	99%	77%	33%	76%	18%
Hispanic	99%	79%	36%	77%	18%
Other	98%	71%	26%	69%	13%
All Groups	98%	74%	33%	73%	16%

[a] None of the SJVAB population is estimated to be exposed to annual average $PM_{2.5}$ concentrations above >18 µg/m^3 with attainment of the annual $PM_{2.5}$ NAAQS.

IV. ADVERSE OZONE AND PM-RELATED HEALTH EFFECTS

Ozone and fine particles ($PM_{2.5}$) have long been associated with adverse health effects, and a growing body of health science literature enables us to quantify how changes in air quality translate into changes in the number of adverse health effects in a population. In order to select specific studies to estimate such changes for the purposes of this study, we consider a number of factors. In particular, to be used a study:

- Must be peer-reviewed.
- Must account for potential confounders such as other pollutants and weather.
- Must use reasonable measures of pollutants.
- Must be based on a population not significantly different from the population being assessed.
- Must provide a basis to estimate changes in an effect that can be valued in economic terms.
- Is preferred if it is more recent, using more advanced analytical methods and reflecting more recent demographics.
- Is preferred if it covers longer periods and larger populations.
- Is preferred if it meets other criteria and is also region-specific.
- Is preferred if it meets other criteria and has been used in previous peer-reviewed benefits assessments.

Given this, we identified seven ozone-related and 14 $PM_{2.5}$-related effects that would be appropriate for inclusion in this study.[3] These effects are summarized in Table IV-1. Those that are quantified here are shaded in gray. Those that are not quantified occur in very small numbers, generally because the population at risk is small or because the concentration-response relationship requires a large change in pollution levels to generate substantial reductions in the effect in the exposed population. For example, we estimate that attaining the NAAQS for $PM_{2.5}$ would result in five fewer cardiovascular hospital admissions annually in the entire eight county region. Summing and including all of those small effects does not change the overall results.

IV. 1 Studies Used in Quantification of Effects

IV.1.1 Developing Health (Concentration-Response) Functions

To quantify the expected changes in health effects associated with reduced exposure to ozone and $PM_{2.5}$, we have used the basic exponential concentration-response (C-R) function developed in the Environmental Protection Agency's Report to Congress (EPA 1999), which evaluates the benefits and costs of emissions controls required by the Clean Air Act.[4]

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[3] Some effects, such as individual respiratory symptoms or eye irritation are not included here because they are at least in part captured by effects such as MRADs, work loss days, school absence days and upper and lower respiratory symptom days. Also, individually they carry relatively small economic values.

[4] The one exception is the case of ozone-related emergency room visits, for which we use a linear concentration-response function.

Specifically, the functional form used is as follows:

$$\Delta C = -C_0(e^{-\beta\Delta P} - 1)$$

where:

ΔC = the change in the number of cases (of a particular health outcome)
C_0 = the number of baseline cases (of the health outcome)
ΔP = the change in ambient pollution concentrations
β = an exponential "slope" factor derived from the health literature pertaining to that specific health outcome.

In most of the recent health literature, "relative risk" factors are reported which relate change in pollution levels to the increased odds of developing various health effects. These risk factors are related to the β in the EPA concentration-response functions in the following manner:

$$\beta = (1 + \text{Increased Odds})/(\text{Change in Pollution})$$

The specific health studies used to develop these β values are described in the following sections.

IV.1.2 Ozone Morbidity

Minor Restricted Activity Days (MRADs)

Minor restricted activity days (MRADs) are days when various (often, respiratory) symptoms reduce normal activities, but do not prevent going to work or attending school. The combination of symptoms that induces an MRAD is more restrictive than any individual symptom. The 1989 study by Ostro and Rothschild, which used a national sample of the adult (18-65) working population over six years (1976-1981) to determine some of the health consequences of ozone and fine particles, is used here. They found an association between ozone and minor restrictions in activity, after controlling for fine particles, that can be used to derive an exponential ozone C-R function. Using a weighted average of the coefficients reported in the analysis, the EPA (2003b) developed a best estimate β coefficient of 0.0022; an annual (baseline) number of 7.8 MRADs per person was also derived from the study. Further following Ostro and Rothschild, we apply this function to the nonelderly, or "working" adult portion of the population. The EPA (2003b) notes that this application is likely to produce a somewhat conservative health outcome estimate, since elderly adults are probably at least as susceptible to ozone pollution as are individuals under the age of 65.

Asthma Emergency Room Visits

Several studies have established a relationship between increases of ozone and a variety of asthmatic symptoms. In one of the more comprehensive works undertaken, Weisel et al. (1995) conducted a five-year retrospective study of the relationship between summer ozone concentrations and asthma-induced emergency room (ER) visits. Specifically, they examined the relationship between ambient ozone levels and ER visits by asthmatics in central and northern New Jersey for five consecutive years (1986 - 1990). A similar study was undertaken by Cody et al. (1992) for the same geographic area and the summer months of 1988 and 1989. While Weisel et al.'s results derive from a single pollutant equation, the Cody et al. study includes SO_2 as a co-pollutant. In each case, though, multiple linear regression analyses were conducted for each year, generating positive and significant coefficients of daily ER visits with ozone concentrations. From these studies' coefficients, the EPA (2003b) derives slope coefficients for a linear concentration-response function. For our analysis, we average these two linear coefficients, resulting in a β value of 0.0323. It is this value that forms the basis for our calculation of reductions in asthma-related emergency room visits from improved ozone levels. The specific function thus developed is as follows:

Δ asthma-related ER visits = (β/ Base Pop) ΔO3 pop,

where: β = ozone coefficient = 0.0323
Base Pop = original studies' baseline population in NJ = 4,436,976
Δ O3 = change in daily 5-hour average ozone concentration (ppb)
pop = the affected population (all ages).

School Absences

Ozone-related school absences is a health outcome that has been examined in two recently published health studies. The first, by Chen et al. (2000), considered the association between air pollution and daily elementary school absenteeism in Washoe County, Nevada, from 1996 to 1998. Student absenteeism was regressed on three air pollutants (ozone, PM_{10} and carbon monoxide), weather variables, and other confounding factors, using autoregression analysis. The second study, by Gilliland et al. (2001), examined 1996 school absences for 12 southern California communities with differing concentrations of multiple pollutants (ozone, NO_2, and carbon monoxide). These researchers used a two-stage time series regression model, controlling for day of the week and temperature, to assess whether there were any associations between pollution levels and absences. Both studies found ozone to be statistically associated with daily absenteeism. More specifically, Chen et al. predicted that for every 50 ppb increase in ozone the overall absence rate increased by 13.01 percent. In contrast, Gilliland et al. found that a 20 ppb increase in 8-hour average ozone concentrations was associated with a 16.3 percent increase in the all-absence rate. From these results, we can derive exponential β values of 0.002446 and 0.00755, which we then average, resulting in an ozone-related school absence concentration-response β value of 0.004998. Finally, EPA (2003b) reports a daily school absence rate of 0.055, obtained from the U.S. Department of Education.

Asthma Attacks

In an early, yet still widely cited, study, Whittemore and Korn (1980) examined daily asthma attack diaries from 16 panels of asthmatics living in six communities of southern California during the mid 1970s. They used multiple logistic regression analysis to test for relationships between daily attack occurrences and daily levels of two types of pollutants (photochemical oxidants and total suspended particulates), plus a variety of weather variables. Results for the two pollutant models showed significant relationships between daily levels of both pollutants and reported asthma attacks. The EPA (2003b) adjusted the model's oxidant results so that they could be used with ozone data. The resulting β value of 0.001843 can then be applied to the asthmatic portion of the Central Valley population, which we assume to be 3.86 percent of the all-age population (as reported in American Lung Association 2002). Finally, a daily incidence rate of wheezing attacks for adult asthmatics of 0.055 is assumed as our baseline rate, based on an analysis of the 1999 National Health Interview Survey (EPA 2003b).

Respiratory Hospital Admissions

For non-elderly (ages 0 – 64), ozone-related respiratory hospital admissions, we turn to a report by Thurston and Ito (1999), which summarized an extensive literature on hospital admissions that included ozone as one of the explanatory variables[5]. In this report, a statistical synthesis of three Canadian studies (Burnett et al. 1994, Thurston et al. 1994 and Burnett et al. 1997a) yielded a quantitative estimate of the respiratory hospital admission effect associated with ozone exposures for the non-elderly general population. Specifically, they calculate a relative risk factor of 1.18 per 100 ppb increase in daily 1-hour maximum ozone levels. From this, we derive a concentration-response β estimate of 0.001655. For respiratory hospital baseline admission rates, we turn to the Office of Statewide Health Planning and Development's Inpatient Hospital Discharge Frequencies for California (2003) and the U.S. National Hospital Discharge Survey (March 2005) to construct age-specific hospital discharge numbers for each county.

To estimate ozone-related avoided incidences of respiratory hospital admissions for patients 65 and older, we generated a pooled β value using several health studies referenced by the EPA (2003b). All of these studies found significant associations between ozone and various categories of respiratory hospital admissions. The studies include: Schwartz (1995), who analyzed the relationship between ozone and all respiratory admissions for the cities of New Haven, Connecticut and Tacoma, Washington; and Moolgavkar et al. (1997), Schwartz (1994a), and Schwartz (1994b), who considered pneumonia and COPD admissions in Minneapolis and Detroit. Our pooled β estimate is equal to 0.004536. Finally, as described for the under-65 case, our county-specific baseline figures come from the California and U.S. Hospital Discharge reports.

IV.1.3 $PM_{2.5}$ Morbidity

Chronic Bronchitis

A case of chronic bronchitis is typically considered to be a recurring condition of mucus in the lungs and wet cough during at least 3 months per year for several years in a row. Abbey et al. (1995) studied the association between fine particles (including $PM_{2.5}$) and new occurrences of these chronic respiratory symptoms in a survey group of nearly 1,900 Californian Seventh Day Adventists. The survey period extended from 1977 to 1987, and the study found a statistically significant relationship between $PM_{2.5}$ and the development of chronic bronchitis in adults aged 27 and over. From this work, the EPA calculated a concentration-response β value of 0.0137 and from an earlier work by Abbey (1993), they obtained an annual bronchitis incidence rate per person of 0.00378. We apply these factors to the proportion of our adult population (27 years of age and older) without chronic bronchitis (which, according to the American Lung Association, is 95.57 percent of the population).

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[5] This is the same approach adopted by ARB (2005).

Minor Restricted Activity Days (MRADs)

As noted above in the ozone morbidity section, minor restricted activity days (MRADs) are days when various (often, respiratory) symptoms reduce normal activities, but do not prevent going to work or attending school. The 1989 study by Ostro and Rothschild noted above used six years (1976-1981) of Health Interview Survey (HIS) data, a large cross-sectional database collected by the National Center for Health Statistics, to determine some of the health consequences of particulate matter and ozone. They also found a statistical association between fine particles and minor restrictions in activity, after controlling for ozone, that can be used to derive an exponential $PM_{2.5}$ C-R function. From the data included in the analysis, the EPA (2003b) developed a $PM_{2.5}$ β coefficient of 0.00741, which is again a weighted average of the coefficients reported in Ostro and Rothschild. As in the ozone case, an annual (baseline) number of 7.8 MRADs per person was derived. Finally, we again apply this function to the non-elderly, or “working” adult portion of the population. As we noted earlier, this application is likely to produce a somewhat conservative health outcome estimate, since elderly adults are probably at least as susceptible to fine particles as are individuals under the age of 65.

Work Loss Days (WLDs)

In a 1987 study, Ostro examined the effect of fine particulate matter on work loss days (WLDs) using a national survey of working adults (aged 18-64) in 49 different metropolitan areas in the United States. He found a significant link between $PM_{2.5}$ and missed days of work for each of the six years of the study (1976-1981), estimating separate coefficients for each year of the analysis. The β coefficient developed by the EPA (2003b) from this work (0.0046) is a weighted average of the coefficients estimated by Ostro, using the inverse of the variance as the weight. In addition, the EPA used a more recent data set (Adams et al. 1999) to determine a daily WLD incidence (baseline) rate of 0.00595, which we use in our analysis.

Acute Bronchitis

Dockery et al. (1996) examined the respiratory health effects of exposure to a number of pollutants, including fine particles, on a sample of over 13,000 children (8-12 years old) from 24 communities in the United States and Canada. Using a two-stage logistic regression model, and adjusting for the potential confounding effects of sex, parental asthma and education, history of allergies, and current smoking in the home, they found $PM_{2.1}$ to be significantly related to cases of bronchitis. From this work, the EPA developed a $PM_{2.5}$ concentration-response function for acute bronchitis in children. The estimated β value of 0.0272 results from combining Dockery et al.’s odds ratio of 1.50 with the study’s observed change in particles of 14.9 $\mu g/m^3$. In addition, the EPA recommends using a baseline incidence rate of 0.043 cases per child per year, as reported by the American Lung Association (2002). Finally, while the Dockery et al. sample focused on children within a 5-year age range, we extend their results to include all school-aged children, based on the assumption that the response of all school-aged children will be similar to those in the study’s more age group.

Lower Respiratory Symptoms

In an earlier health study, Schwartz et al. (1994) used logistic regression and found a statistical association between lower respiratory symptoms (defined as cough, chest pain, phlegm and wheeze) in children and a number of pollutants, including PM_{10}, acid aerosols, gaseous pollutants, and fine particles. The study was conducted in six cities over a five-year period (1984-1988) and considered a sample of over 1,800 students enrolled in grades two through five. More recently, Schwartz and Neas (2000) replicated the earlier analysis, focusing their efforts on $PM_{2.5}$. In a model that also included coarser particulate matter ($PM_{10-2.5}$), an odds ratio of 1.29 was associated with a 15 $\mu g/m^3$ change in $PM_{2.5}$. From this work, we generate an exposure-response function, with an estimated β value of 0.01698 and a daily baseline rate of 0.0012. Finally, while the Schwartz and Neas work is suggestive of an age range from 7 to 14, we again extend these results to include all school-aged children because the response of older teenagers and younger children is likely to be similar to the children in the studied cohort.

Upper Respiratory Symptoms

In a study of Utah school children (ranging in age from 9 to 11), Pope et al. (1991) examined the association between daily occurrences of upper respiratory symptoms and daily PM_{10} concentrations. A day of upper respiratory symptoms was defined as consisting of one or more of the following symptoms: runny or stuffy nose; wet cough; and burning, aching, or red eyes. Using logistic regression, the study found that PM_{10} was significantly associated with upper respiratory symptoms. The EPA (2003b) used this work to develop a concentration-response function with a β estimate of 0.0036. We convert this PM_{10}-derived β value to its $PM_{2.5}$ counterpart (0.0072) and also rely on Pope et al.'s daily upper respiratory symptom incidence rate per child of 0.3419. Finally, we note that the sample size in the Pope et al. study was quite small, and is most representative of the asthmatic children's population, not the total school-aged population. We therefore apply this exposure-response function only to asthmatic children, who are assumed to represent 11 percent of the total children's population in the San Joaquin Valley.

IV.1.4 $PM_{2.5}$ Mortality

The scientific literature that assesses associations between $PM_{2.5}$ and premature mortality in adults has expanded rapidly over the past decade, with several large scale multi-city studies that extend or reanalyze earlier studies (for example, Pope et al. 1995; Krewski et al. 2000; Pope et al. 2002) as well as a California-specific study that focuses on the Los Angles basin (Jerrett et al. 2005). To estimate $PM_{2.5}$ - related mortality for the SJV requires determining which of these studies is most appropriate for conditions in this region. In general, as noted above, studies are preferred that: are peer reviewed, cover longer periods, are more recent (better reflecting current demographics and lifestyles), include larger samples, account for confounding factors, and were conducted in locations that have the greatest similarity to the study population. There is also an increasing literature that measures (Woodruff et al. 1997) or indicates the probability of (Loomis et al. 1999; Pereira et al. 1998; Wang et al. 1997; Chay and Greenstone 2003) an association between $PM_{2.5}$ and mortality in children less than one year of age.

Both EPA and ARB have conducted recent benefit assessments for $PM_{2.5}$ reduction (EPA 2003; EPA 2004; EPA 2005; ARB 2005), and these assessments have also undergone peer-review of the analytical approaches used, including the choice of C-R functions. The consensus is that for national studies Pope et al. (2002) is the preferred basis to estimate adult mortality. The EPA Science Advisory Board Health Effects Committee (SAB-HEES) (2004) further recommends that neonatal mortality now be included in the base analysis using the C-R function from Woodruff et al. (1997). For California, there is agreement that Pope et al. provides the best C-R function from the national literature, but there is also agreement that Jerrett et al. (2005) likely better represents California (ARB 2005 and peer-review comments thereon). Following the professional consensus, and based on the reasons discussed below, we rely on these three studies to estimate mortality effects. We use Pope et al. for the primary analysis, Jerrett et al. as a sensitivity test for adult mortality, and Woodruff et al. as an indicator of neonatal mortality, but outside the primary analysis and aggregate results.

Pope et al. (2002)

This study meets all of the essential criteria noted above for the choice of a C-R function. It is a large-scale, longitudinal cohort study that follows a large nationally representative population (ages 30 and older) across 61 cities over a 16 year follow-up period from a base of 1979-1983. Extending the follow-up period to 16 years increases the mortality data set by a factor of three compared to earlier studies. This study also includes $PM_{2.5}$ measurements from 1999 and the first three quarters of 2000, and controls more closely for a series of personal risk factors, including lifestyle and occupation. The increase for the all-cause mortality associated with annual average $PM_{2.5}$ is 6% per 10 $\mu g/m^3$.

Woodruff et al. (1997)

This is the first comprehensive national study to assess the impact of fine particles (PM_{10}) on infant mortality in the United States. It includes a sample size of four million infants less than one year of age across 86 metropolitan areas for the interval 1989-1991. Overall, the study estimates an increase of 4% for all-cause infant mortality for every 10 $\mu g/m^3$ increase in PM_{10}. The EPA SAB-HEES (2004) now recommends that neonatal mortality be included in primary benefit analyses conducted by EPA, and that the Woodruff et al. C-R be used. The Woodruff study, however, did not include infants in a number of states, including California (because maternal education levels were not reported for California). While the study is likely representative of national conditions, it is impossible to determine whether the omission of California infants makes it less representative of the California population. Consequently, for the purposes of this study we do not include post neonatal deaths in the primary benefit analysis.

Jerrett et al. (2005)

This study is based on the Los Angeles area population subset from the national cohort included in Pope et al. (2002), accounts for the same confounders, and also assesses the association between average annual $PM_{2.5}$ and differences in mortality in the age 30 and older population. The authors find a substantially higher association between $PM_{2.5}$ and mortality, with a 17% increase in all-cause mortality for every 10 $\mu g/m^3$ increase in $PM_{2.5}$. While this is quite a large difference, contrasted with the 6% increase found by Pope et al. for the overall national population, there are sound reasons to conclude that the results better represent the Los Angeles Basin population. A primary reason is that Jerrett et al. use a detailed intraurban exposure measure supported by 23 $PM_{2.5}$ monitors across the region. This contrasts with the national cohort studies that compare interurban exposure and have much less spatial resolution. Another is that traffic-generated primary particles have a greater association with observed effects, and traffic in the Los Angeles basin accounts for nearly five times the proportion of total primary particles emitted as in the rest of the United States, at 3.7% compared to 0.75%.

For purposes of assessing benefits in the SJV, the Jerrett et al. work is more appropriate than Pope et al. in that the exposure measure more closely fits the approach that we use in REHEX. However, because it is specific to the Los Angeles area population and the profile of traffic-related PM emissions in that region, we take the more conservative approach of relying on Pope et al. for our primary assessment and provide estimates based on Jerrett et al. as a sensitivity test. This is also the approach recommended by a peer-review group recently asked by ARB to consider the use of the Jerrett et al. result for a regulatory analysis (ARB 2005; Appendix A).

IV. 2 Estimates of Reduced Adverse Health Effects with Attainment of the NAAQS

Reductions in the numbers of adverse effects vary with the degree to which the baseline period pollution levels exceed the standards, the size of the population at risk, and the size of the association between a change in pollution and triggering the effect. A further factor is the age of the population included in the underlying health science study. So, for example, while it is reasonable to think that chronic bronchitis might be caused by $PM_{2.5}$ exposure in the population under age 27, the study that we rely on only includes ages 27 and older, so the large population of those under that age is treated as if this effect could not occur in that group. The same is true for $PM_{2.5}$ -related mortality, where the population under age 30 is not included in the number of estimated annual deaths. Also, premature mortality, with a small risk factor, will not be as frequent an effect as one such as school absences, which carries a larger risk.

The number of pollution-related effects that would be avoided if the NAAQS of ozone and $PM_{2.5}$ were met are discussed and summarized below. The economic benefit and the aggregate value of reducing these effects are discussed in Section V.5 below.

IV. 2.1 Reductions in Ozone-Related Effects

The reductions in effects that would be expected with attainment of the ozone NAAQS are shown in Table IV-2. Typically, there are fewer of the more severe effects and fewer effects in smaller groups (for example, the population age 65 and older). However, while there are relatively few reductions in ozone-related hospital admissions, at 260 per year, this is an effect with considerable impacts on patients and their families. The relatively larger numbers of days of avoided school absences, 188,000, reflects the larger population and the sensitivity of children to ozone. For the age 5-17 population of 783,740 this suggests that on average one in four children experiences a day of absence each year due to elevated ozone levels.

IV.2.2 Reductions in $PM_{2.5}$ - Related Effects

$PM_{2.5}$ - related effects are shown in Table IV-3. The most serious consequences of exposure to fine particles over the health-based standards are associated with $PM_{2.5,}$ and this is reflected in the estimated gain of nearly 500 deaths averted each year. To put this in perspective, we estimate that 130 people die earlier than they would each year in Fresno County. In 2001-2003 an average of more than 180 people died in that county in motor vehicle accidents (DHS 2005). This means that reducing pollution can account for the equivalent of avoiding two thirds of the motor vehicle deaths there, similar to the proportions in Kern and Stanislaus Counties. This illustrates the real consequences of elevated fine particle levels, and the substantial gains from attaining the NAAQS. The contribution of $PM_{2.5}$ exposure to premature mortality, relative to reported motor vehicle deaths, is shown by county in Table IV- 4 below.

The avoidance of chronic bronchitis, an illness that can significantly limit activity, is also noteworthy at 325 cases a year. Asthmatic children also avoid more than 16,000 additional days of upper respiratory symptoms (in addition to ozone-related school absences and asthma attacks). Children also experience fewer cases of acute bronchitis.

The economic value and aggregate benefits of avoiding these effects by attaining the NAAQS is discussed in Section V below.

Table IV-1 Health endpoints

Ozone	$PM_{2.5}$
School absences Ages 5-17	Acute bronchitis Ages 5-17
Emergency room visits All ages	Lower respiratory symptoms in children Ages 5-17
Respiratory hospital admissions Under age 65	Upper respiratory symptoms in children Ages 5-17 asthmatic population
Respiratory hospital admissions Ages 65 and older	Respiratory hospital admissions Ages 65 and older
Asthma hospital admissions All ages of the asthmatic population	Premature death (mortality Ages 18-64
Asthma attacks All ages of the asthmatic population	Asthma ER visits Under age 18
Premature death (mortality) All ages	Minor restricted activity days All ages
Minor restricted activity days Ages 18-64	Onset of chronic bronchitis Ages 27 and older
	Non-fatal heart attacks Ages 18 and older
	Cardiovascular hospital admissions Ages 18 and older
	Neo-natal mortality Under age 1
	Asthma emergency room visits Under age 18 asthmatic population
	Work loss days Ages 18-64
	Asthma hospital admissions Ages 64 and under

Table IV-2 Ozone-Related Effects

	Fresno	Kern	Kings	Madera	Merced	San Joaquin	Stanislaus	Tulare	Total
Respiratory Hospital Admissions Ages 0-64	55	45	10	10	10	15	20	30	195
Respiratory Hospital Admissions Ages 65+	25	15	0	5	5	0	5	10	65
Respiratory Hospital Admissions All ages	80	60	10	15	15	15	25	40	260
Asthma Attacks Asthmatic population all ages	5,900	4,700	900	1,100	1,300	1,500	1,900	3,000	23,300
Emergency Room Visits All ages	20	15	5	5	5	5	5	10	70
School Absences Ages 5-17	34,000	28,700	4,900	6,000	8,000	8,200	9,300	18,400	117,500
Days of School Absences Ages 5-17	54,500	45,900	7,800	9,600	12,800	13,100	14,900	29,400	188,000
Minor Restricted Activity Days Ages 18-64	49,900	38,200	9,000	9,200	10,800	13,200	16,200	24,600	171,100

Table IV-3 $PM_{2.5}$-Related Effects

	Fresno	Kern	Kings	Madera	Merced	San Joaquin	Stanislaus	Tulare	All Counties
Minor Restricted Activity Days Ages 18-64	4,610	3,800	870	880	1,050	2,070	2,160	1,840	17,280
Premature Mortality Ages 30 and older	130	100	15	15	20	65	65	50	460
Work Loss Days Ages 18-64	800	660	150	150	180	360	380	320	3,000
Lower Respiratory Symptoms Ages 5-17	240	195	35	40	60	100	105	100	875
Upper Respiratory Symptoms Asthmatic Children	4,440	3,670	660	760	1,100	1,860	1,940	1,880	16,310
Acute Bronchitis Ages 5-17	860	750	130	140	210	390	360	390	3,230
Chronic Bronchitis Ages 27 and older	85	75	15	15	20	40	40	35	325

Table IV-4 $PM_{2.5}$ - Related Deaths Compared to Motor Vehicle Deaths

County	Annual $PM_{2.5}$ - Related Deaths	Annual Motor Vehicle Deaths[6]	$PM_{2.5}$ as % of MV
Kern	100	144	70%
San Joaquin	65	111	59%
Stanislaus	65	97	67%
Merced	20	54	37%
Madera	15	37	41%
Fresno	130	181	72%
Kings	15	34	45%
Tulare	50	89	56%
Total	460	747	62%

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[6] Annual average from 2001-2003.

V. ECONOMIC VALUATION

V. 1 The Basis for Value

If we know how much illness and premature death might be avoided as a result of meeting the health-based air quality standards, why assign monetary values at all, and what is the basis for those values? First, there are more worthwhile things to do than either society or individuals can afford. As a result, we choose among the things that we do. The social choice to control emissions in order to improve air quality and health is one of these things, and one that is a high priority for Californians. It is therefore useful to have a sense in economic terms of the scale of gains from successfully implementing pollution control policies and programs. This study is designed to provide a measure of these gains that is transparent, uses the best available information, reflects social preferences and can readily be compared against the value of other social choices.

The basis for each value begins with the premise that, within limits[7], society accepts individual choices as valid, and as reflecting the value that individuals place on their choices, whether it is which news channel to watch or which college is best for their child to attend. That is, what an individual chooses to do accurately represents what is best for him or her, and for society, which is simply the sum of the individuals that make up that society. Social value – what we want to capture here – is then simply the sum of value to individuals. To determine the value to individuals of reducing pollution-related health risks we use prices or implied prices when available, along with survey (contingent valuation) results.

One objective of this study is to provide a monetary, or dollar, measure of the benefits that would accrue from avoiding some of the adverse health effects that result from exposure to unhealthful air. A critical aspect of such a measure is determining the value that society places on avoiding specific adverse effects. These range from symptoms that are fairly minor, such as eye irritation, through hospitalization, emergency room visits, asthma attacks and the onset of chronic bronchitis, to premature death. Individuals value reducing these effects to avoid:

- Loss of time (work and school) and the direct medical costs that result from avoiding or responding to adverse health effects.
- The pain, inconvenience and anxiety that result from adverse effects, or efforts to avoid or treat them.
- Loss of enjoyment and leisure time.
- Adverse effects on others resulting from their own adverse health effects.

V. 2 Concepts and Measures of Value

Ideally, measures of value would represent all of the losses to individuals and to society that result from adverse health effects. They would also accurately reflect actual preferences and decision-making processes similar to those we use daily to make basic choices. Our decisions

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[7] Most people readily accept limits on individual choices that are necessary to protect others. This includes things such as criminal statutes, speed laws, and a variety of environmental protections ranging from vehicular exhaust standards to protection of endangered species.

about which goods or services to buy are based on which items give the most satisfaction, or utility, relative to prices and income. Market prices are therefore accepted as reasonable measures of the value of those items that can be purchased. However, there is no market in which cleaner air (like many other environmental goods) can be bought. Consequently, values for such goods cannot be directly observed from prices. Economists have developed alternatives to market prices to measure the value of environmental improvements, including health benefits resulting from cleaner air.

Two generally accepted measures of the value of changes in well-being due to reducing the adverse health effects of air pollution are the cost of illness (COI) measure and the willingness to pay (WTP) or willingness to accept (WTA) measures. All three measures have limitations but, when taken together, they yield a generally accepted range of values for the health benefits of improvements in air quality. In this study, we use the most appropriate available value for each health endpoint.

V. 2.1 Cost of Illness

The COI method was the first to be developed and described in the health and safety literature as a basis to value reductions in risk. It requires calculating the actual direct expenditures on medical costs, plus indirect costs (lost wages), incurred due to illness. This method is still the primary measure used to value the benefit of avoiding hospital admissions and other medical treatments. The COI method has the advantage of being based on real dollars spent to treat specific health effects and the actual market value of work time. Since it includes only monetary losses, however, and does not include losses associated with the value of leisure time, of school or unpaid work time, or of general misery, it does not capture all of the benefits of better health. The method is therefore generally viewed as limited and representing a lower bound on value. The basic limitation is that it is a measure of the *financial* impact of illness, not the *change in well being* due to illness, since financial loss is only part of the value forfeited by illness and discomfort. Other factors, most notably pain, inconvenience and anxiety, associated with illness can result in a significant disparity between COI estimates and WTP (or WTA) estimates. As discussed below, the COI approach has been shown to produce a lower-bound value estimate. Overall, COI measures are used when more complete measures are unavailable for a specific effect. While they generally represent a lower bound of value, using them allows the valuation of some adverse effects, such as emergency room visits, which might otherwise not be quantified.

V. 2.2 Market Based Values

Because we know that COI measures undervalue adverse health effects, many studies have been conducted to determine more complete values. For improvements in health, we use WTP measures, which are both more complete than COI and consistent with accepted economic concepts about markets and individual economic choices. Market choices that reduce risks to health or life indirectly indicate the WTP for lower risks, or the WTA for higher risks. Values derived from this method are based on relating differences in wages or consumer costs to differing degrees of risk. Those differences indicate the demand for and the WTP for lower risk, or the WTA for greater risk. Because air quality is not a market commodity and has no observable market price, many of the values used in benefit assessments for environmental improvements depend on studies of market-determined wage differentials and consumer expenditures in relation to lower risk of harm from other causes. These differentials and expenditures are then surrogates for the market price for reduced risk of harm from air pollution.

There is an extensive economics literature assessing the value of reduced workplace risk of death. It is, however, important to control for factors other than risk that can influence wage differentials, such as unpleasant working conditions. Studies conducted in the past 20 years do control carefully for job attributes that are not related to differences in risk. (Viscusi 1992, 1993, 2004; Viscusi and Aldy 2003) There is a smaller literature that investigates differences in consumer expenditures relative to risk of injury or death associated with product use. The results for the most carefully conducted work, which controls for product characteristics other than relative risk, are generally consistent with the wage-risk studies (Atkinson and Halvorsen 1990; Viscusi 1992).

V. 2.3 Contingent Valuation

When values inferred from markets are not available, another means to estimate value involves the use of surveys. This method is referred to as contingent valuation (CV) because people are asked to determine what something would be worth *as if* they were able to purchase or sell it. CV has become a significant source of values over the past two decades, as the methodology has matured and become more accepted, and as policy-makers (and the courts) have become more interested in the application of economic values to decision-making. CV-based values, as with wage-risk based WTA values, are conceptually better than COI because they are more inclusive. Respondents can value loss of enjoyment and discomfort, as well as the direct costs of an adverse health effect. The survey approach is, however, expensive to administer and the validity of values derived from this method depends on careful design and application of the survey instrument. Nonetheless, CV measures are in many cases well-supported and add useful information to benefits assessment (Carson et al. 2001).

V. 2.4 Strengths and Limitations of Methods

The most appropriate basis for valuing reductions in adverse health effects is presently WTP values based on CV studies and WTA based on wage-risk studies (Viscusi 1993). Cost of illness measures are used when preferred measures are unavailable because a lower bound value is preferable to zero value, which is implied when an effect is not included in the benefits assessment. We use four criteria to choose specific values from the literature.

1. The value used should be appropriate for the type of risk. For example, involuntary risk might carry a higher value than voluntary risk. The degree of risk (1 in 10,000 or 1 in 1,000,000) is a factor, as is whether the risk of harm in increasing or decreasing. Whether harm is prospective or has already occurred is also a factor.[8]

2. A measure should be as complete as possible. That is, it should represent gains or losses in well-being as fully as possible.

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[8] The human capital method used in damage award legal cases is not used here, for example, because harm has already occurred. In assessing the benefits of environmental improvements we are considering the avoidance of harm, not compensation for harm.

3. If similar values are derived from studies using different methods, for example from market-based studies and CV studies, those values are given a greater weight on the premise that convergence implies a closer representation of true value.
4. If more than one valid study produces values that are similar for comparable adverse affects, those values are given greater weight.

Given these criteria, CV results for WTP are most highly ranked for appropriateness and validity, followed by WTA from wage-risk studies (supported by WTP from a valid consumer behavior study) and then COI measures.

V. 3 Specific Values for Premature Death

Premature mortality is the most significant effect of exposure to unhealthful levels of air pollution that can presently be quantified. Consequently, determining a socially appropriate value to attach to reducing the risk of premature mortality is a crucial part of any benefit assessment. It is very important to keep in mind that we are not valuing the life of any identifiable individual, but rather the value of reducing a very small risk over a large population enough so that some people would live longer than would otherwise have been the case.

V.3.1 The Concept of the Value of a Statistical Life

Wage-risk studies tell us how much more compensation workers must be paid to accept jobs with very slightly elevated risks of job-related death. Consider this example:

There are 10,000 workers and the annual risk of job-related death is 1/10,000 greater than in a lower wage job. This means that we would expect one job-related death in this group annually (10,000 x 1/10,000). Let's say that each worker is paid $700 a year more as a result of this risk, and workers not facing this risk are paid $700 a year less than those at risk. The implied value of reducing risk just enough to prevent one death is $700 x 10,000 = $7,000,000. This is what economists call the value of a statistical life (VSL). Studies of consumer choices and product risk are based on the same approach – the small difference that each consumer pays to reduce a slight risk aggregated to the level of reducing risk enough to prevent a single death.

V.3.2 The Range of Values

There is a very wide range across all studies that assess VSL. However, this range can be narrowed significantly by considering characteristics of the population in each study relative to the population with which we are concerned (the San Joaquin Valley), and by reviewing the methods used in each study. In a recent meta-analysis of VSL from US wage-risk studies (Viscusi and Aldy 2003), most estimates fell into the range of $3.8-$9.0 million (in 2000 dollars) with a median for "prime-aged workers" of $7 million. This range is also consistent with the most robust consumer choice study (Atkinson and Halvorsen 1990), which found a VSL of $5.1 in 2000 dollars. Contingent valuation studies produce values at or above the upper end of the Viscusi and Aldy meta-analysis (Viscusi 1993; Jones-Lee 1976).

V.3.3 Issues in Selecting Specific Values

To assess the value to society of reducing the risk of premature death associated with elevated levels of air pollution, we want a value that is based on risk of a similar scale (in this case a very small annual risk) and is based on the preferences of people similar to the population at risk from pollution exposure. The need to match the degree of risk and population characteristics as closely as possible raises several issues, largely relating to factors such as age and income.

V.3.3.1 Groups Most at Risk

For mortality, we have evidence for the very young – newborns – and those aged 30 and over associating elevated pollution with premature death. We also know that the very young, those whose health is already compromised, and those aged 65 and older are at greater risk than the general population.

V.3.3.2 Age and the Value of Life

Because wage-risk studies are based largely on blue collar workers, they reflect the preferences of younger workers, and not those outside the workforce who are very young or older, but who are likely at greater risk of early death related to air pollution. Since younger people have longer life expectancies, using a VSL based on their preferences might overstate the appropriate VSL for the older. Similarly, it is likely to understate society's value for young children, as several studies indicate that parents and society more broadly place greater value on preventing harm to children than to adults. Further, to the extent that blue collar workers have incomes below the average, their job choices might reflect a lower VSL than would be the case for white collar workers. Complicating this further, older adults are more likely to experience impaired health and could therefore have a lower VSL than is the case for a healthy younger or middle-aged adult or a child, although evidence suggests that this effect, if any, is small (Alberini et al. 2004). In determining which VSL to use to value air quality improvements, these factors are all considered.

The most recent research regarding health status and older age (Alberini et al, 2004) finds no strong evidence that VSL declines significantly with age, and then only at age 70 and above. Further, those with underlying health conditions report little difference in VSL than those who are healthier. At the other end of life, there is evidence (Dickie and Messman 2004; EPA 2003a and the references therein) that families and society place a higher value on children's well-being, but there is no well established basis to adjust adult values to account for this. Although these are some studies that assess how much more we are willing to pay for children's health, there has been little work regarding how we value their lives.

Consistent with these findings and the recommendations of peer-review advisory groups, benefit assessments carried out for proposed federal and state rules and programs (EPA 2003b, 2004, 2005; ARB 2005) do not make any adjustment for age or health status.

V.3.4 The Value of a Statistical Life Used in this Study

As noted above, the convergence of values from US-based wage-risk studies is $3.8 to $9.0 million in 2000 dollars. Converting this to 2005 dollars (using the US all-item CPI) produces a range of $4.3 to $10.2 million. The value from a consumer choice study is $5.8 million in 2005 dollars.

The most recent final EPA regulatory analysis (EPA 2005) used $5.5 million in 1999 dollars. Converting this to 2005 dollars gives us $6.5 million. We further adjust this for the increase in per capita income in California from 1999 to 2004[9], and assume an income elasticity of 0.5[10] (Viscusi and Aldy 2003). This leads to a VSL of $6.7 million, which is the value used in this study.

V. 4 Specific Values for Health Endpoints

Generally accepted values for many endpoints have been developed over the past decade and are widely used in benefit assessments and regulatory analyses by USEPA and the states. These values have been peer-reviewed by advisory bodies, including committees of EPA's Scientific Advisory Board, and many have also been published in the peer reviewed literature. We generally follow this established protocol, adjusting specific values for inflation and California-specific incomes. Where California-specific COI data are available, as for hospitalizations, we use those values.

Onset of Chronic Bronchitis

Apart from premature death, the onset of chronic bronchitis is one of the most serious adverse effects that is associated with PM exposure and is quantifiable. The value of avoiding this effect has been estimated in two CV studies (Krupnick and Cropper 1989; Viscusi et al. 1991) and is $374,000 in current dollars, beginning with the value used by EPA (2003b; 2004; 2005) to account for the severity of the disease relative to the underlying studies.

Hospitalizations

Respiratory-related hospitalizations are costly both in terms of treatment and loss of work, household and leisure time. We use a California-based value derived from Chestnut et al. (2006), of $32,000 per admission. While Chestnut et al. assessed the COI and WTP for adults, we apply this value to the entire population because when children are hospitalized, one or more adults faces the opportunity cost of time diverted from work, caring for other children and other normal activities.

Minor Restricted Activity Days

Willingness to pay to avoid a day when normal activities are limited by a combination of pollution-related symptoms derives from Tolley et al.'s 1986 study, reported by EPA (2005) as

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[9] The most recent final data available.

[10] As incomes rise, consumers place greater value on many goods. The degree to which this value rises with income and leads to more consumption of a good is called income elasticity. While EPA most recently used 0.4 as the adjustment for this effect, Viscusi and Aldy found that the appropriate value for the income elasticity of VSL is 0.5-0.6.

$51 in 1999 dollars and 1990 income. ARB (2005) converted this to current dollars and adjusted for income, yielding a value of $61 per MRAD.

Work Loss Days

Apart from MRADs, when productivity might be lower, some work days are lost outright as a result of $PM_{2.5}$ exposure. These days are valued at the daily wage rate for each county, ranging from $123 in Merced to $141 in Kern and San Joaquin (EDD 2003).

School Absence Days

To value days of school absence, Smith et al. (1997) estimated lost productivity to the adult care-giver, under the assumption that one adult stayed home to take care of the sick child. In situations where two caregivers were involved, the lower income was used to estimate lost productivity. In cases where only one adult had an income (about 39 percent of the cohort studied), an imputed value for household work was used.

Using this methodology, Smith et al. estimated the total indirect cost of 3.6 million school loss days to be $194.5 million (in 1994 dollars) This translates into a per-day value of $54.03 (again, in 1994 dollars).

To apply these national figures to our analysis, two adjustments were then made. First, the value was updated to 2005 dollars. Second, it was modified to reflect wage levels in the SJV. This is the approach adopted by EPA (2005) and used by Hall et al. (2003). This method produces a range of values from $65 in Tulare County to $79 in San Joaquin County.

Upper and Lower Respiratory Symptom Days

For these effects we adjusted the value that EPA (2005) has adopted, again adjusting for income and inflation to 2005 values. A lower respiratory symptom day is valued at $20 and an upper respiratory day at $32.

Acute Bronchitis

Bronchitis typically involves multiple symptoms and each occurrence has a duration of about six days (EPA 2005). To construct a value for this effect, we combine Loehman et al.'s (1979) values for chest discomfort and cough and update this number to 2005 dollars, producing a value for one day of $18.30. Over a six day period, this reaches a total of $110.

Asthma Attack

This effect is valued based on a 1986 CV study conducted in Los Angeles (Rowe and Chestnut) that estimated WTP to avoid a "bad asthma day." Adjusting EPA's most recent peer-reviewed figure to current dollars and adjusting for income, this value is $50 per event.

Emergency Room Visits

Emergency room visits are valued at $335 in 2005 dollars based on two combined COI studies (EPA 2005). This dollar measure does not include time lost at work or school, or the value of avoiding the pain and anxiety caused by the underlying condition and ER visit.

V. 5 Estimated Economic Value from Reduced Adverse Health Effects with Attainment of the NAAQS for Ozone and $PM_{2.5}$

Unsurprisingly, given the great value that individuals and society more broadly place on life, the overall benefits of attaining the NAAQS are dominated by premature mortality. Across the Valley 460 people are estimated to avoid premature death each year, accounting only for the effect of $PM_{2.5}$ and only for the population age 30 and older. With a value for each life of $6.7 million, this effect alone offers a benefit of attainment of more than $3 billion each year. While this consequence of elevated fine particle levels is by far the most striking, other effects are also important.

For example, an additional 325 new cases of chronic bronchitis annually could be avoided with attainment of the $PM_{2.5}$ NAAQS. At a value of $374,000 each – reflecting the significant costs of treatment and loss of enjoyment and activity – avoiding this effect would generate benefits of over $120 million annually. Ozone attainment offers thousands fewer school absence days, conservatively valued at nearly $13 million a year. It should be noted that this only reflects the value of time lost to an adult caregiver and not any medical costs or loss of educational opportunity. Minor restricted activity days (MRADs) would cost adults over 190,000 days a year when their daily routine is limited to some degree by exposure to elevated ozone or $PM_{2.5}$. Avoiding this offers an economic benefit over $10 million annually.

Tables V-1 and V-2 show the overall benefits, both in numbers of effects and in dollars for ozone and for $PM_{2.5}$, respectively. Looking at the overall benefits, residents of the San Joaquin Valley could expect annual benefits of $3.2 billion if both the ozone and $PM_{2.5}$ NAAQS were attained.

It is also worth considering the per capita benefits, to provide a sense of perspective. On a Valley-wide average, annual benefits are nearly $1,000 per person. This varies across counties with the levels of pollution and the size of the more vulnerable populations, and very slightly with income (which determines or influences the value of some effects). The county-level average benefits per resident range from nearly $650 in Merced County to over $1,200 in Kern County.[11]

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[11] Fresno $1,124; Kern $1,209; Kings $785; Madera $679; Merced $645; San Joaquin $789; Stanislaus $973; Tulare $1,020; all counties $970.

Table V-1 Ozone-Related Effects and Economic Value

	Fresno	Kern	Kings	Madera	Merced	San Joaquin	Stanislaus	Tulare	Total
Respiratory Hospital Admissions Ages 0-64	55	45	10	10	10	15	20	30	195
Respiratory Hospital Admissions Ages 65+	25	15	0	5	5	0	5	10	65
Respiratory Hospital Admissions All ages	80	60	10	15	15	15	25	40	260
Value(millions)	$2.56	$1.92	$0.32	$0.48	$0.48	$0.48	$0.8	$1.28	$8.32
Asthma Attacks Asthmatic population all ages	5,900	4,700	900	1,100	1,300	1,500	1,900	3,000	23,300
Value(thousands)	$295	$235	$45	$55	$65	$75	$95	$150	$1,015
Emergency Room Visits All ages	20	15	5	5	5	5	5	10	70
Value (thousands)	$6.70	$4.31	$1.68	$1.68	$1.68	$1.68	$1.68	$3.35	$23.45
School Absences Ages 5-17	34,000	28,700	4,900	6,000	8,000	8,200	9,300	18,400	117,500
Days of School Absences Ages 5-17	54,500	45,900	7,800	9,600	12,800	13,100	14,900	29,400	188,000
Value(millions)	$3.60	$3.12	$0.53	$0.66	$0.87	$1.03	$1.13	$1.91	$12.85
Minor Restricted Activity Days Ages 18-64	49,900	38,200	9,000	9,200	10,800	13,200	16,200	24,600	171,100
Value(millions)	$3.04	$2.33	$0.55	$0.56	$0.66	$0.80	$0.99	$1.5	$10.43
Total Value in Millions	$9.5	$7.61	$1.45	$1.76	$2.08	$2.39	$3.02	$4.84	$32.64

Table V-2 $PM_{2.5}$-Related Effects and Economic Value

	Fresno	Kern	Kings	Madera	Merced	San Joaquin	Stanislaus	Tulare	All Counties
Minor Restricted Activity Days Ages 18-64	4,610	3,800	870	880	1,050	2,070	2,160	1,840	17,280
Value(thousands)	$281.2	$231.8	$53.1	$53.7	$64.1	$126.3	$131.8	$112.2	$1,054.2
Premature Mortality Ages 30 and older	130	100	15	15	20	65	65	50	460
Value(millions)	$871.0	$670.0	$100.5	$100.5	$134.0	$435.5	$435.5	$335.0	$3,082.0
Work Loss Days Ages 18-64	800	660	150	150	180	360	380	320	3,000
Value(thousands)	$106.0	$93.1	$21.0	$19.8	$22.0	$50.8	$52.0	$39.7	$403.8
Lower Respiratory Symptoms Ages 5-17	240	195	35	40	60	100	105	100	875
Value(thousands)	$4.8	$3.9	$0.7	$0.8	$1.2	$2.0	$2.1	$2.0	$17.5
Upper Respiratory Symptoms Asthmatic Children	4,440	3,670	660	760	1,100	1,860	1,940	1,880	16,310
Value(thousands)	$142.1	$117.4	$21.1	$24.3	$35.2	$59.5	$62.1	$60.2	$521.9
Acute Bronchitis Ages 5-17	860	750	130	140	210	390	360	390	3,230
Value(thousands)	$94.6	$82.5	$14.3	$15.4	$23.1	$42.9	$39.6	$42.9	$355.3
Chronic Bronchitis Ages 27 and older	85	75	15	15	20	40	40	35	325
Value (millions)	$31.8	$28.1	$5.6	$5.6	$7.5	$15.0	$15.0	$13.1	$121.6
Total Value in Millions	$903.4	$698.6	$106.2	$106.2	$141.6	$450.8	$450.8	$348.4	$3,206

VI. CONCLUSIONS AND IMPLICATIONS

Conclusions

Almost every resident of the San Joaquin Valley regularly experiences air pollution levels known to harm health and to increase the risk of early death. For example, from 2002 through 2004 each person was on average exposed to unhealthful levels of ozone on 70 days a year. Even in the county with the lowest exposure (San Joaquin County) residents were exposed to levels over the California 8-hour standard on ten days each year. In Kern County, this rises to over 100 days each year. This is unsurprising, given how frequently and pervasively the health-based air quality standards are violated. These exposures translate directly into poorer health and an elevated risk of premature death. Further, some groups are more at risk than the average, with Hispanics experiencing six more days of ozone exposure above the California air quality standard than the average resident.

Some other noteworthy results of the analysis include:

- Valley-wide, the economic benefits of meeting the federal $PM_{2.5}$ and ozone standards average nearly $1,000 *per person per year*, or a total of more than $3 billion.

This dollar value represents the following:

- 460 fewer premature deaths among those age 30 and older
- 325 fewer new cases of chronic bronchitis
- 188,400 fewer days of reduced activity in adults
- 260 fewer hospital admissions
- 23,300 fewer asthma attacks
- 188,000 fewer days of school absence
- 3,230 fewer cases of acute bronchitis in children
- 3,000 fewer work loss days
- More than 17,000 fewer days of respiratory symptoms in children

To place the reduction in premature deaths in perspective, attaining the federal $PM_{2.5}$ standard would be the equivalent of reducing motor vehicle deaths by over 60% Valley-wide, and by more than 70% in Fresno and Kern Counties.

Implications

Residents of the San Joaquin Valley face significant public health risks from the present unhealthful levels of ozone and fine particles. This is in addition to other health challenges, including a high rate of poverty, which exceeds 30% in Fresno County, compared to a statewide rate below 20%. The region overall would experience substantial economic and health gains from effective policies to reduce pollution levels. For the more populous and more polluted areas in Kern and Fresno Counties, this is even more pronounced. Attaining the California air quality standards, which are more protective of health, would double the health benefits listed above.

The adverse impacts of air pollution are not distributed equally. Both Hispanics and non-Hispanic blacks are exposed to more days when the health-based standards are violated. Residents of Fresno and Kern Counties experience many more days when the $PM_{2.5}$ standards are violated than the Valley-wide average. Tulare County joins Fresno and Kern in being well above average for the number of days of exposure above the ozone standards. Children under age 5 are exposed to ozone concentrations above 70 ppb on more days than older adults.

Because ozone is elevated during the summer months, and the $PM_{2.5}$ 24-hour standard is typically violated more frequently in the winter months, there is no “clean” season in this region.

As the population continues to increase, with associated increases in vehicle traffic and economic activity, the gains from attaining the health-based air quality standards will grow, but also become more difficult to achieve. Identifying and acting on opportunities now would produce substantial gains to the people of the Valley.

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APPENDIX

A.1 The Benefits of Attaining the California Ambient Air Quality Standards

The state health-based standards for ozone and $PM_{2.5}$ provide a greater degree of protection than do the federal standards. Consequently, the benefits of attaining the California Ambient Air Quality Standards (CAAQS) are significantly larger. While the present focus is on attainment of the NAAQS, there is clear evidence that health will continue to be impaired until the CAAQS are also attained. The health-related benefits of attaining the ozone CAAQS are shown in Table A-1. $PM_{2.5}$–related benefits are shown in Table A-2. It should be noted that there is no separate state 24-hour standard for $PM_{2.5}$, so only effects associated with longer term (annual average) exposure are included here. Generally, attaining the California standards would approximately double the gains that will result from meeting the NAAQS.

Table A-1 Reductions in Ozone-Related Health Effects Resulting from CAAQS Attainment

	Fresno	Kern	Kings	Madera	Merced	San Joaquin	Stanislaus	Tulare	Total
Respiratory Hospital Admissions Ages 0-64	120	85	15	20	20	35	40	60	395
Respiratory Hospital Admissions Ages 65+	55	35	5	10	10	0	10	25	150
Respiratory Hospital Admissions All ages	175	120	20	30	30	35	50	85	545
Value(millions)	$5.60	$3.84	$0.64	$0.96	$0.96	$1.12	$1.60	$2.72	$17.44
Asthma Attacks Asthmatic population all ages	12,600	9,300	1,900	2,300	2,800	3,500	4,200	6,100	42,700
Value(thousands)	$630	$465	$95	$115	$140	$175	$210	$305	$2,135
Emergency Room Visits All ages	30	20	5	5	5	10	10	15	100
Value (thousands)	$8.61	$5.74	$1.44	$1.44	$1.44	$2.87	$2.87	$4.31	$28.72
School Absences Ages 5-17	78,200	59,900	11,000	13,800	18,900	19,800	22,200	38,800	262,600
Days of School Absences Ages 5-17	125,100	95,800	17,600	22,100	30,200	31,700	35,500	62,100	420,100
Value(millions)	$8.26	$6.51	$1.20	$1.52	$2.05	$2.50	$2.70	$4.04	$28.80
Minor Restricted Activity Days Ages 18-64	96,800	69,400	16,100	18,100	21,000	27,400	31,700	43,900	322,400
Value(millions)	$5.90	$4.23	$0.98	$1.10	$1.28	$1.67	$1.93	$2.68	$19.80
Total Value in Millions	$20.40	$15.06	$2.92	$3.71	$4.44	$5.47	$6.44	$9.74	$68.18

Table A-2 Reductions in $PM_{2.5}$ -Related Health Effects Resulting from CAAQS Attainment

	Fresno	Kern	Kings	Madera	Merced	San Joaquin	Stanislaus	Tulare	Total
Premature Mortality Ages 30 and older	240	180	30	30	40	120	130	110	880
Value(millions)	$1,608.0	$1,206.0	$201.0	$201.0	$268.0	$804.0	$871.0	$737.0	$5,896.0
Acute Bronchitis Ages 5-17	1,540	1,290	240	250	380	740	700	780	5,920
Value(thousands)	$169.4	$141.9	$26.4	$27.5	$41.8	$81.4	$77.0	$85.8	$651.2
Chronic Bronchitis Ages 27 and older	155	130	30	30	35	80	75	75	610
Value (millions)	$58.0	$48.6	$11.2	$11.2	$13.1	$29.9	$28.0	$28.0	$228.1
Total Value in Millions	$1,666.2	$1,254.7	$212.2	$212.2	$281.1	$834.0	$899.1	$765.1	$6,124.7

A.2 Sensitivity Analysis by Endpoint

The results presented in Sections IV and V above report a mid-value for each effect, based on a professional consensus regarding the concentration-response relationships that “best” represent the association between exposure and resulting adverse health effects. It is generally accepted, however, that the real association lies within a range. Here we present the results of sensitivity tests that estimate benefits based on such a range, generally based on 95% confidence intervals. Unsurprisingly, this analysis produces a wide range in the results, and the results are shown in Tables A-3 and A-4.

There is one noteworthy result, which is the high estimate for premature mortality, indicating over 1,200 deaths a year associated with violations of the NAAQS for $PM_{2.5}$, in contrast to 460 estimated with the mid-range concentration-response function. The difference results entirely from the use of Pope et al.’s (2002) central value for the “base” case and Jerrett et al.’s (2005) result for the high case. As noted in section IV, Jerrett et al. is likely a better representation of risk for the SJV population than is the Pope et al. result, a conclusion reached by several peer reviewers who addressed this question recently for ARB (CARB 2005).

Table A-3 Ozone-Related Effects Low and High Case Ranges

Adverse Effect	All Counties – Range of Effects	All Counties – Range of Value
Respiratory Hospital Admissions All ages	150-360	$4,800,000 – 11,520,000
Asthma Attacks Asthmatic population all ages	4,670-35,690	$233,500 – 1,785,000
Emergency Room Visits All ages	40-80	$11,480 – 22,960
Days of School Absences Ages 5-17	88,560-282,300	$3,786,000 – 12,070,000
Minor Restricted Activity Days Ages 18-64	69,500-270,400	$4,240,000 – 16,490,000

Table A-4 $PM_{2.5}$-Related Effects Low and High Case Ranges

Adverse Effect	All Counties – Range of Effects	All Counties – Range of Value
Minor Restricted Activity Days Ages 18-64	14,070-20,460	$858,270 - $1,248,060
Premature Mortality Ages 30 and older	160-1,220	$1,072,000,000 - $8,174,000,000
Work Loss Days Ages 18-64	2,540-3,470	$342,800 – 466,400
Lower Respiratory Symptoms Ages 5-17	195-1510	$3,900-30,000
Upper Respiratory Symptoms Asthmatic Children	2,770-29,370	$88,640 – 939,800
Acute Bronchitis Ages 5-17	1,240-5,070	$136,400 – 557,700
Chronic Bronchitis Ages 27 and older	165-480	$61,710,000 - $179,500,000