# *Economic Valuation of Ozone-Related School Absences in the South Coast Air Basin*

**Final Report**

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## ABSTRACT

Ozone levels in the South Coast Air Basin of Southern California have fallen substantially over the past decade, but the region continues to violate state and federal air quality standards on a significant number of days. The recent health literature reports associations between ozone and school absences, among other adverse effects on children. Estimates are reported here of differences in: the number of days of all illness-related absences and the number of days of respiratory-illness related absences; the direct economic loss to families of those absences; and the economic loss resulting from respiratory-related hospitalizations and asthma-related emergency room visits. Differences in the number of these effects associated with improvements in air quality are reported for the interval 1990-92 to 1997-99 and for rolling three-year intervals to 1997-99 across that period. The benefits of reduced absences resulting from future attainment of the state 1-hour standard are also estimated. The population cohort is children aged 5-18 residing in the South Coast Air Basin in 1998.

The results show that there have been significant benefits to schoolchildren in the South Coast Air Basin as ambient ozone levels have fallen over the past decade. For the 1998 school-aged population, there would have been more than three million more school absences annually in 1999 had ozone levels not decreased from the baseline interval of 1990-92 to 1997-99 levels. As population increased and more children enrolled in year round and summer school programs, the benefits of ozone reductions increased relative to air quality improvements. The economic value of fewer school absences ranges from $156 million annually to more than $330 million annually, with a best estimate of $245 million. This represents a benefit of nearly $75, on average, for every school child in the region.

## ES.0 EXECUTIVE SUMMARY

Although ozone concentrations have fallen substantially in the South Coast Air Basin of Southern California, the health-based state air quality standards are still violated on more than 100 days a year. Children are one of the groups most sensitive to ozone, and the Air Resources Board has been directed by the state legislature to consider whether children are adequately protected when establishing and reviewing environmental standards.

While it has been known for decades that ozone contributes to adverse health effects in children, and that reducing concentrations therefore results in health benefits, only recently has significant attention been paid to the economic value of those benefits. Increasingly, legislative and regulatory bodies seek information on the economic benefits of environmental protection, especially in contexts where substantial improvements have already occurred. In addition, recent advances in health research provide the necessary concentration-response functions to support economic valuation of an important adverse health effect in children: school absences.

In this context, this assessment of the economic benefits of reducing school absences as a result of attaining the state ozone standard provides information that could help to establish more concretely the benefits to be expected from attainment of the state air quality standard.

Estimates are generated of reductions in: the number of days of all illness-related absences and the number of days of respiratory-illness related absences; the economic loss to families of absences; and the economic loss resulting from respiratory-related hospitalizations and asthma-related emergency room visits. Differences in the number of these effects associated with improvements in air quality are reported for the interval 1990-92 to 1997-99 and for rolling three-year intervals to 1997-99 across that period. The benefits of reduced absences resulting from future attainment of the state 1-hour standard are also estimated. The population cohort is children aged 5-18 residing in the South Coast Air Basin of Southern California.

### ES.1 Methods

Estimating the health benefits of reducing children's exposure to ambient ozone is based on integrating data on air quality and population with concentration-response relationships for specific adverse health effects to first estimate the change in the number of such effects. An economic value per unit of each effect is then used to produce a measure of the dollar value of changes in the number of effects in the population. The sequence in which estimation is done begins with modeling exposure in the relevant cohort, in this case children aged 5-18, then applying concentration-response relationships from the health science literature to estimate changes in the numbers of pollution-related effects and, finally, determining an appropriate dollar value to assess the economic benefits of reduced numbers of effects.

To estimate benefits on an annual basis, we need to know the distribution of air pollutant concentrations spatially and temporally, how many people are exposed to these concentrations, and for how many days. For the purposes of this study, the primary measure of exposure is the number of children exposed to ozone concentrations above the California air quality standards in each of a series of three-year intervals, beginning in 1990-92 and ending in 1997-99. Three-year rolling averages are used to dampen the effects of year-to-year weather variability on air quality trends. The Regional Human Exposure model is used to estimate changes in exposure. The Symptom-Valuation model, using concentration-response functions from the peer-reviewed health literature, estimates the changes in adverse health effects that the population experienced as a result of changing exposure to air pollution. Finally, the estimated reductions in adverse health effects are converted to economic benefit estimates using generally accepted dollar values for each effect.

## ES.2 Results

The regional annual benefits estimated to result from lower concentrations of ambient ozone that reduced school children's exposure to levels above the state air quality standard are centered on nearly $255 million. The components of this total benefit are shown in Table E.1.

**Table E.1 Benefits of decreases in annual ozone-related emergency room visits, respiratory-related hospital admissions, and school absences from 1990-1992 to 1997-1999.**

| Symptom | Basin | Los Angeles County | Orange County | Riverside County | San Bernardino County |
|---|---|---|---|---|---|
| Number of emergency room visits | 167 | 108 | 16 | 17 | 26 |
| Number of hospitalizations | 387 | 237 | 38 | 42 | 70 |
| Value of adjusted emergency room visits and hospitalizations | $9,985,000 | $6,121,000 | $980,000 | $1,082,000 | $1,802,000 |
| Number of school absences | 3,190,000 | 1,824,000 | 282,000 | 430,800 | 653,400 |
| Value of school absences | $245,048,000 | $147,689,000 | $21,584,000 | $30,109,000 | $45,666,000 |
| TOTAL | $255,033,000 | $153,810,000 | $22,564,000 | $31,191,000 | $47,468,000 |

Since the purpose of this analysis is to determine how many fewer effects there are now than there would have been had air quality not improved significantly, the 1998 population is used as a baseline measure.

The results show that there have been significant benefits to schoolchildren in the South Coast Air Basin as ambient ozone levels have fallen over the past decade. For the 1998 school-aged population, there would have been more than three million more school absences annually in 1999 had ozone levels not decreased from the baseline interval of 1990-92 to 1997-99 levels. As population increased and more children enrolled in year round and summer school programs, the benefits of ozone reductions increased relative to air quality improvements. The economic value of fewer school absences ranges from over $150 million annually to more than $330 million annually, with a best estimate of $245 million. This represents a benefit of nearly $75, on average, for every school child in the region.

While falling ozone levels in the 1990s clearly contributed to significant benefits to the health of schoolchildren, the Basin continues to have many days each year when the state 1-hour ozone standard is violated. Consequently, attainment of the standard would generate additional significant benefits, reducing school absences by nearly one million annually, with an economic value of about $68 million.

**ES.3 Conclusions**

As the school-aged population increased and year round and summer school programs expanded from 1990-1999, ozone-related school absences would have significantly increased had ambient ozone levels not fallen significantly. The economic value of the approximately 3.2 million absences avoided annually is more than $255 million. Ozone levels continue, however, to exceed one or more health-based standards in much of the region, indicating that continuing air quality improvements will generate substantial further benefits for the school-aged population, reducing absences by almost another one million each year.

## 1.0 INTRODUCTION

Although ozone concentrations have fallen substantially in the South Coast Air Basin (SoCAB) of Southern California over the last decade, the health-based state air quality standards (AQS) are still violated on a significant number of days a year. Children are one of the groups most sensitive to ozone, and the Air Resources Board (among other agencies) has been directed by the state legislature to consider whether children are adequately protected when establishing and reviewing environmental standards.

While we have known for decades that ozone contributes to adverse health effects in children, and that reducing concentrations therefore results in health benefits, only recently has significant attention been paid to the economic value of those benefits. Increasingly, legislative and regulatory bodies seek information on the economic benefits of environmental protection, especially in contexts where substantial improvements have already occurred. In addition, recent advances in health research provide the necessary concentration-response functions to support economic valuation of an important adverse health effect in children: school absences.

In this context, this assessment of the economic benefits of reducing school absences as a result of attaining the state ozone standard provides information that could help to establish more concretely the benefits to be expected from attainment of the state AQS.

Estimates are generated of reductions in: the number of days of all illness-related absences and the number of days of respiratory-illness related absences; the economic loss to families of absences; and the economic loss resulting from respiratory-related hospitalizations and asthma-related emergency room visits. Differences in the number of these effects associated with improvements in air quality are reported for the interval 1990-92 to 1997-99. To highlight the decline in ozone levels across the decade results are also reported for rolling three-year intervals to 1997-99 across that period. The population cohort is children aged 5-18 residing in the South Coast Air Basin of Southern California (SoCAB). Results are reported for the basin overall and for each of the four counties in the basin. The benefits of attaining the 1-hour state standard are also estimated.

### 1.1 Methods

We used the research methods that were first developed to assess the economic benefits of attaining the NAAQS in the SoCAB in the late 1980s (Winer et al., 1989; Hall et al., 1989; Hall et al., 1992), and have since been used in other regions (Hall et al., 1994; Lurmann et al., 1999), with particular reference to school-aged children and ozone-related school absences and related adverse health effects. The basic approach has four steps:

1. The cohort population is identified and the ambient air quality data are spatially mapped to the 5 x 5 kilometer grid with the cohort population.
2. The annual number of children-days of exposure above various concentration thresholds is computed by grid square for variety of metrics, such as the daily 1-hr maximum, the 10 A.M. – 3 P.M. average, and the 10 A.M – 6 P.M. average, using the Regional Human Exposure (REHEX) model. The number of children-days of exposure over the state standard is calculated, as well as the differences between exposure concentrations and the standard.
3. An epidemiologically based exposure-response function (Gilliland et al., 2001) is linked to the exposure estimates via the Symptom Valuation (SYMVAL) module to generate an estimate of the difference in the number of school absences as ozone levels fell how many fewer school absences would be expected if the state standards were met. Similar linkages are made for respiratory-related hospitalizations and asthma-related emergency room visits.
4. Economic values from the published literature, and commonly used in benefit estimation (U.S. EPA, 1999; 2001) are then updated and used to calculate the economic value of the expected differences in absences, and other health outcomes

### 1.1.1 Exposure Estimation and Decreased Adverse Effects

Steps one and two were undertaken by Sonoma Technology, Inc. (STI) under contract to the South Coast Air Quality Management District (SCAQMD). Using the most recent population, ozone, and exposure data files, STI applied the REHEX model to generate files in a format that we used in steps 3 and 4.

Step three was accomplished by integrating exposure estimates with the most recent research results from the Children's Health Study directed by Dr. John Peters at the University of Southern California. A 20 ppb difference in the 10 A.M. – 6 P.M. ambient ozone concentrations is associated with a 62.9 percent increase in illness-related absences, and an 82.9 percent increase in respiratory illness-related absences (Gilliland et al., 2001). Researchers at the University of Southern California worked cooperatively with researchers on this project to ensure that their results are fully reflected in the benefit assessment. The SYMVAL model developed by STI generated estimates of how many fewer school absences would be expected with attainment, and how many fewer were experienced in the interval 1997-1999 compared to 1990-1992 as a result of declining ozone concentrations in the SoCAB. Decreases in hospitalization and emergency room visits were also estimated using the SYMVAL model in a similar manner. The effects threshold was assumed to be 70 ppb for 10 A.M. – 3 P.M. and 10 A.M. – 6 P.M. average concentrations and 90 ppb for 1-hr daily maximum concentrations. .

### 1.1.2 Economic Valuation

Step four was carried out by first updating an existing database of economic values associated with the consequences of school absences and of children's respiratory illnesses, hospitalizations and emergency room visits. Despite all of the environmental health risks faced by children, relatively little work has been done on the economic valuation of these adverse health effects. Most of the existing economic literature has focused on adult health, with little investigation of how adults' valuations of their own health apply to children. However, a number of studies do present some estimates of the economic benefits of improving children's health.

In particular, Smith et al. (1997) provide a detailed examination of national health care cost and resource use by persons with asthma. They use the cost of illness (COI) technique to account for direct medical expenditures, which include payments for hospital inpatient stays and emergency room visits, and indirect medical costs resulting from missed work or missed school days. From this work, we derive not only dollar estimates for emergency room visits, but also for ozone-related school absences. For both health outcomes, point estimates and 95 percent confidence intervals are reported, allowing us to construct low, mid, and high dollar estimates. To develop a dollar estimate for a respiratory hospital admission, we use information from the 1999 California Hospital Discharge Data, a data collection that contains annual, non-confidential hospital patient discharge data for the State of California. These data are edited by the California Office of Statewide Health Planning and Development and verified by individual hospitals. Profiled variables include patients' length of stay, major diagnostic category, and total charges.

## 1.2 Goals of the Study

The overall goal of the study is to provide a sound basis to assess a potentially important benefit of improvements in ozone levels from 1990 to 1999 for school-aged children living in the SoCAB. We also estimate the future benefits of continuing improvements in air quality as the AQS for ozone are attained. Because continuing efforts to attain the state and federal ozone standards have required substantial emissions reductions, and future attainment will require additional efforts, it is useful to have measures of expected benefits in terms of reduced numbers of effects and the economic value of those reductions.

## 2.0 METHODS

Estimating the health benefits of reducing children's exposure to ambient ozone is based on integrating data on air quality and population with concentration-response relationships for specific adverse health effects to first estimate the change in the number of such effects. An economic value per unit of each effect is then used to produce a measure of the dollar value of changes in the number of effects in the population. The sequence in which estimation is done begins with modeling exposure in the relevant cohort, in this case children aged 5-18, then applying concentration-response relationships from the health science literature to estimate changes in the numbers of pollution-related effects and, finally, determining an appropriate dollar value to assess the economic benefits of reduced numbers of effects.

### 2.1 Exposure Modeling

The Regional Human Exposure (REHEX) Model is a computer model designed to estimate population exposure to various air pollutants. This model was first developed to support assessment of the economic benefits of attaining air quality standards in the SoCAB (Winer et al., 1989; Hall et al., 1992). It has also been used to investigate the pattern of pollution exposure across demographic groups (by income, age and ethnicity) in the SoCAB (Brajer and Hall, 1992; Fruin et al., 2001), and to assess human exposure in other regions, including the San Francisco Bay Area (Lurmann and Korc, 1994) and Houston, Texas (Lurmann et al., 1999). The model can use ambient air quality data or model output as inputs for exposure estimation. For this research, ambient air quality data were used. The model was used to estimate ambient or outdoor exposure because all of the exposure-response functions used to quantify health effects in this study where developed using ambient air quality as a surrogate for actual exposure. Indoor ozone exposures are almost always lower than ambient exposure and children spend the majority of time indoors. Typical indoor - outdoor differences in ozone exposure are essentially accounted for in the exposure response functions selected for use in the study.

To quantity health benefits of air quality improvements, we need to first assess the population's exposure to the pollutant(s) of interest in the baseline and later-year periods. To estimate benefits on an annual basis, we need to know the distribution of air pollutant concentrations spatially and temporally, how many people would have been exposed to these concentrations, and for how many days. For the purposes of this study, the primary measure of exposure is the number of children that would have been exposed to ozone concentrations above the California air quality standards (AQS) in each of a series of three-year intervals, beginning in 1990-92 and ending in 1997-99. Three-year rolling averages are used to dampen the effects of year-to-year meteorological variability on air quality trends. Three years is sufficient to smooth out atypical years when pollutant levels are influenced by unusual weather conditions. The 1998 population aged 5-18 is then mapped against pollution levels at the 5x5 km grid level to determine the number of exposures above the threshold levels.

After exposure in the base and future intervals are calculated, the Symptom-Valuation (SYMVAL) model (Lurmann and Kumar, 1996) estimates the changes in adverse health effects that the population is expected to experience as a result of changing exposure to air pollution. The model can estimate the symptoms for a single pollution exposure case or, as in this study, the symptoms for two or more exposure cases so that the *difference* in adverse effects associated with different exposure patterns for the same population can be assessed. For policy purposes, the later application is more useful and this is the way the model is generally used. In order to calculate changes in the number of adverse health effects, SYMVAL is applied using concentration-response functions derived from the health science literature, as described in section 2.2.

### 2.1.1 Air Quality

The air quality database consisted of the hourly ambient ozone concentrations measured at 48 monitoring stations located in and around the SoCAB. These data were obtained from the ARB Air Quality CD, Version 11. The hourly values were spatially mapped to a 325 x 200 km grid of 5 x 5 km squares extending from UTM easting coordinates of 275 to 600 km and UTM northing coordinates of 3670 to 3870 km. The mapping algorithm employed inverse distance-square weighting of concentrations from the three closest stations within 150 km of each grid centroid. However, if data were available from a single air quality station located within 5 km of a gird centroid, these data alone were assigned to the grid square. This monitoring network and database provide good spatial coverage in the populated portions of the SoCAB.

### 2.1.2 Population and School Enrollments

The population data were obtained from the 1990 and 2000 Bureau of the Census databases for population-by-age for each census block. The census block populations were mapped to grids using ARC-INFO gridding algorithms for polygon data. The grids with nonzero populations are shown in Figure 2.1. Intermediate year populations were estimated by exponential interpolation, assuming constant population growth rates in each grid between 1990 and 2000. All of the health benefit analysis was constructed using the estimated 1998 population of children aged 5-18, because the objective was to determine how many fewer adverse effects occurred in that population in the 1997-1999 interval, compared to the number that would have occurred had ozone levels not fallen from earlier years. *So, differences represent how many fewer effects occurred in the 1998 population as a result of ozone levels falling to 1997-1999 levels, compared to the number of effects that would have occurred in that population had ozone levels remained at the 1990-92 concentrations*. The 1998 population for this cohort is shown in Table 2.1.

**Table 2.1 The SoCAB population aged 5-18 in 1998**

| Region | Population |
|---|---|
| Los Angeles County | 1,995,548 |
| Orange County | 555,618 |
| Riverside County | 331,328 |
| San Bernardino County | 400,926 |
| South Coast Air Basin | 3,283,429 |

Total "traditional" public school enrollments, by county, were obtained from the California Department of Education's DataQuest Website for1998. These are shown in Table 2.2.

However, given the significant growth in year-round programs and in summer school programs throughout the study area during this time period, a careful accounting of "when" students were in class had to be made. The various year-round programs, summer school programs, and the exact calculations and adjustment procedures used are discussed in the following section.

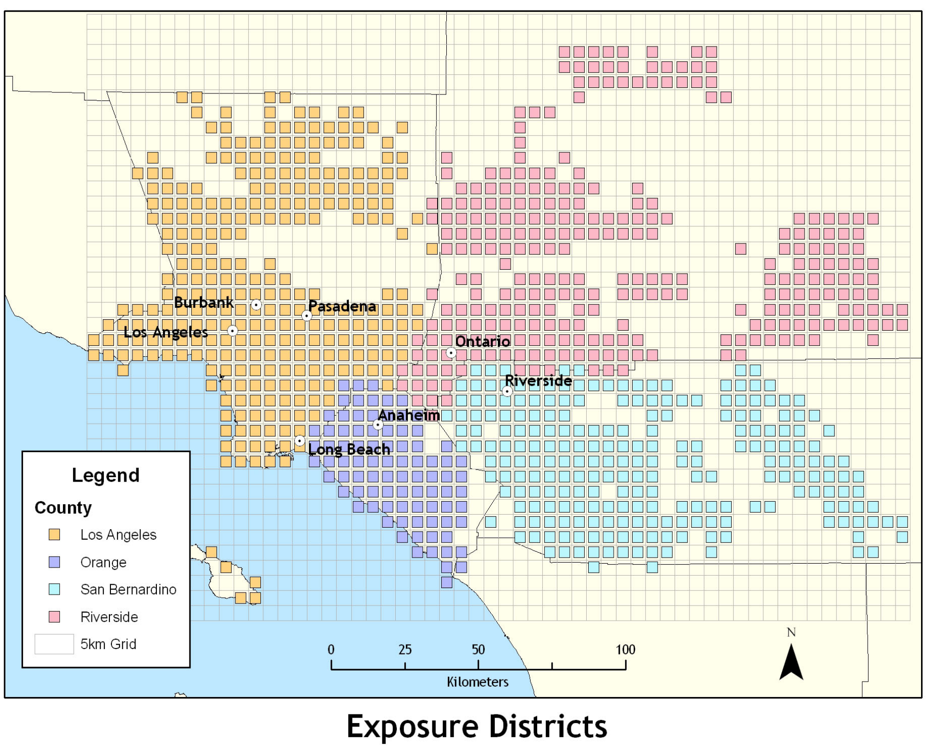


**Figure 2.1. Population exposure districts included in the modeling domain.**

**Table 2.2 1998 School enrollments by type and by county**

| County | Public School | | | Private School |
|---|---|---|---|---|
| | Traditional School Schedule | Year-Round School Schedule | Summer School | |
| Los Angeles | 1,203,664 | 282,237 | 198,605 | 346,228 |
| Orange | 399,396 | 45,583 | 87,867 | 85,565 |
| Riverside | 202,907 | 62,345 | 28,407 | 36,347 |
| San Bernardino | 233,149 | 82,723 | 32,641 | 45,906 |

**Year-Round Education**

Year-round education is an alternative way to construct the school calendar. Whereas the traditional school calendar is divided into nine and a half months of instruction and two and a half months of vacation during the summer (providing 180 days of class time), year-round calendars break these instructional/vacation blocks into shorter units. The 60/20 calendar is the most typical pattern followed (sixty days of instruction followed by twenty days of vacation), with the 45/15, and the Concept 6 (roughly eighty days of instruction followed by forty days of vacation) also being used by many districts. In all of these year-round patterns, students are still offered 180 instructional days, with the exception of the Concept 6 program--its students only receive 167 instructional days per year. An obvious advantage of such a year-round system is that it expands the seating capacity of a school facility. Because of rapid population growth and classroom overcrowding, the number of school districts using year-round education has grown significantly over the last decade.

Detailed year-round school enrollment figures for October 2000, at the district level, were obtained from the California Department of Education's (CDE) Website. Then, using CDE state figures for year-round enrollment for the time period from 1990-2000, we determined that a 9.65 percent annual growth rate characterized statewide year-round enrollments over the decade. Assuming that our four-county study area demonstrated comparable growth, we "backcasted" year-round enrollments for the SoCAB basin.

Finally, to perform SYMVAL runs for the population of school-aged children, we had to determine how many year-round education, and summer school students, are predicted to be in class on any given day of the year. As noted above, a number of different year-round programs are utilized in the four-county area. By carefully recording the numbers of each type of program followed in each county, a weighted average could then be calculated. This weighted average allowed us to determine, on any given school day of the year, what percentage (and what absolute number) of year-round students were supposed to be in attendance. The resulting specific percent figures for

Los Angeles, Orange, Riverside and San Bernardino Counties are 67 percent, 72 percent 71 percent and 71 percent, respectively.

**Summer School**

An important portion of total enrollments occurs during the summer months, even in districts with little or no year-round education. Summer school enrollments typically range between ten to thirty percent of regular student enrollments, and moreover, these summer school enrollments take place during the warmer months of the year, when ozone levels are generally higher. However, this information is not compiled at the state, or county, levels. To construct an estimate of summer school enrollments, we were forced to turn to individual school districts. Based on figures provided by school district representatives in some of the larger districts (Los Angeles Unified, Saddleback Valley Unified, and San Bernardino City Unified provided the most detailed information), we constructed an approximation of summer school enrollment, by county, for 1999. Then, using detailed annual enrollment information obtained from selected districts for the entire decade, we again "backcasted" estimates for enrollments for all four counties.

**Private School Enrollment**

The private school enrollment for 2000 was estimated from the difference between the total population reported by the Bureau of the Census and the total public school enrollment for each county. The estimates were then backcast to earlier years. This category may also include some home-schooled children, some children attending college, and some children who left school before age eighteen. The private school enrollment is estimated to be 10 to 17 percent of the 5-18 year old children population. All of the private school students were assumed to follow the traditional school schedule.

Figure 2.2 shows how the estimated percentage of children in school for various time periods, including those in private schools. The estimates for 2000 indicate that about 91 percent of children are in school during the traditional school year and 17 to 26 percent are in school during the summer. In 1990, only 8 to 20 percent of the children were in schools during the summer.

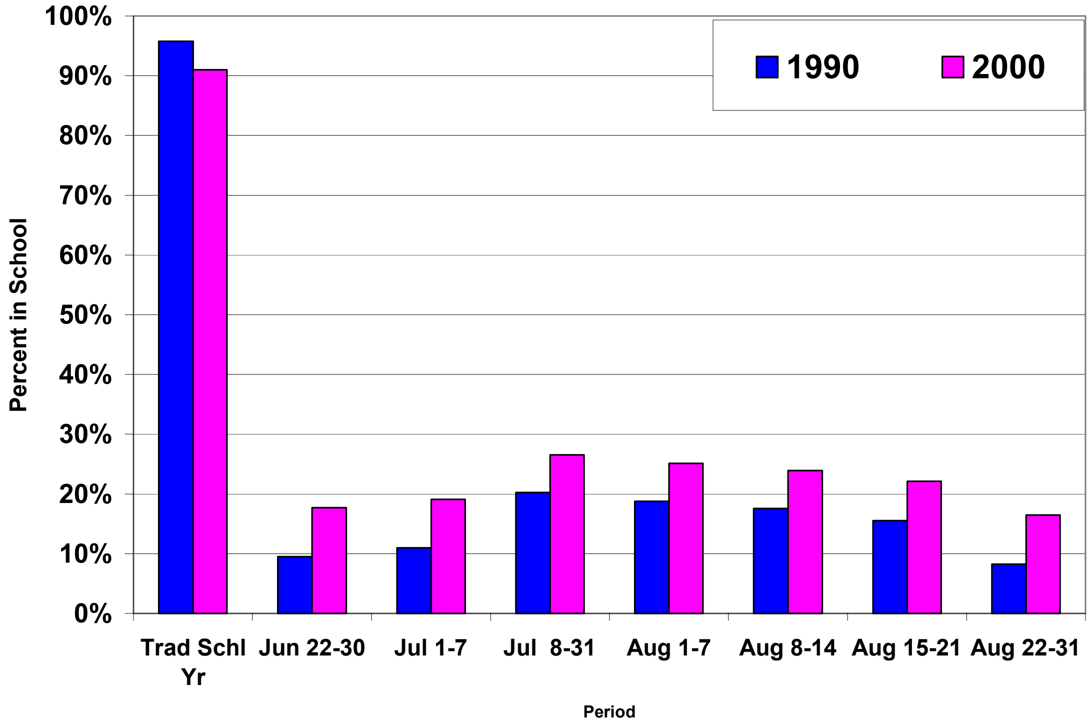


**Figure 2.2. Percentage of 5-18 year old children in the SoCAB attending school in various time periods.**

### 2.1.3 Exposure Estimates

The estimated number of person-days per year of children's exposures to 1-hr daily maximum ozone concentrations above 90, 120, 150, and 200 pbb are shown in Figure 2.3. These exposures are calculated by combining each year's air quality (for all days of the year) with the spatially mapped population for the individual years. The estimated exposures show a strong downward trend over the 1990 to 1999 period for all of the thresholds levels. The numbers of 1-hr exposures above 90 ppb for the two 3-year averaging periods are shown in Figure 2.4. We estimate 212 and 250 million exposures per year to daily 1-hr maximum values above 90 ppb in 1990-1992 with the 1991 and 1998 populations, respectively. In the 1997-1999 period, we estimate 75 million exposures per year to daily 1-hr maximum values above 90 ppb using the 1998 population.

Figure 2.5 shows the number of children's exposures on school days to 10 A.M. – 6 P.M. ozone concentrations above thresholds ranging from 70 to 150 ppb by year. These estimates are also based on school-day populations for the individual years. They indicate a reduction from 83 million per year in 1992 to 17 million per year in 1998-1999 in children's exposures above 70 ppb on weekdays. The numbers of 8-hr (10 A.M. – 6 P.M.) exposures above 70 ppb for the two 3-year averaging periods are shown in Figure 2.6. We estimate 73 and 87 million exposures per year in 1990-1992 with the 1991 and

1998 populations, respectively. In the 1997-1999 period, we estimate 22 million exposures per year to daily 8-hr values above 70 ppb using the 1998 population. These represent remarkably large reductions in ozone exposures for any urban area during a period with significant population growth.

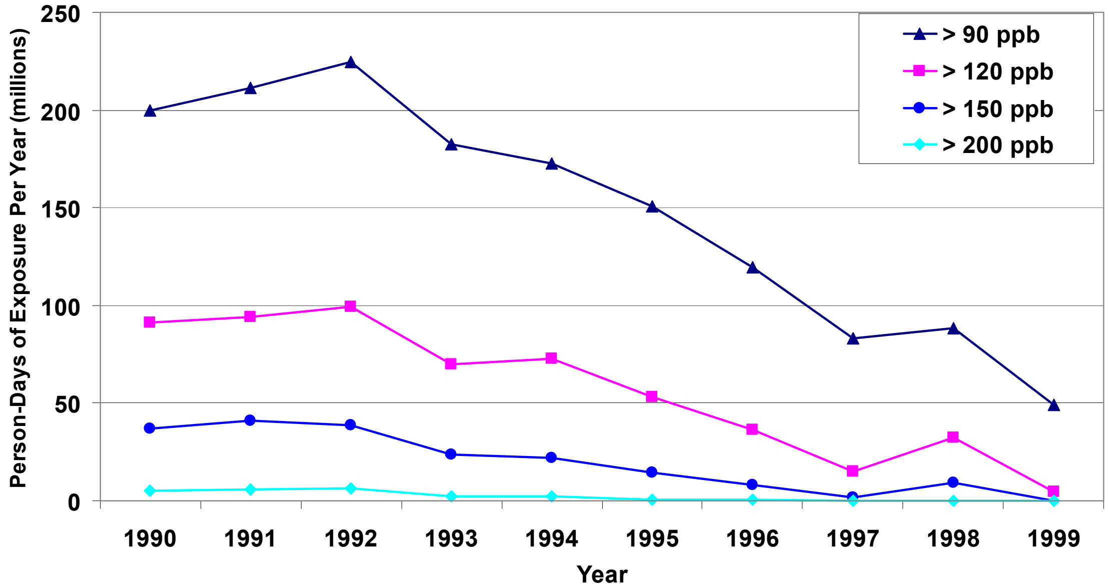


**Figure 2.3 Estimated 1-hr maximum ambient ozone exposures for children.**

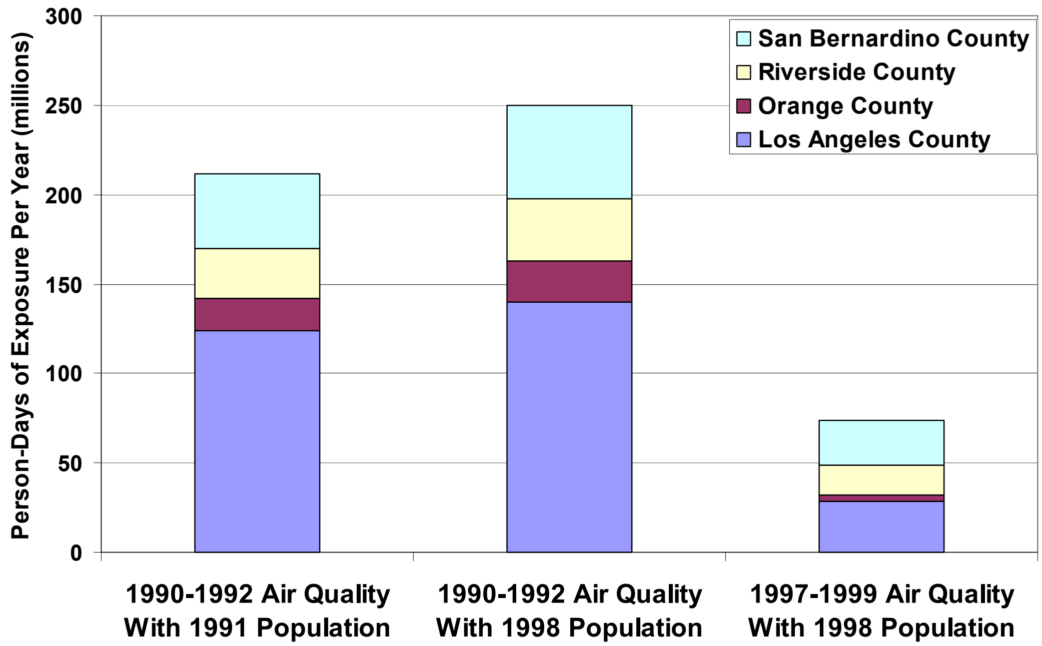


**Figure 2.4 Estimated number of 1-hr maximum exposures above 90 ppb for children in the SoCAB by county.**

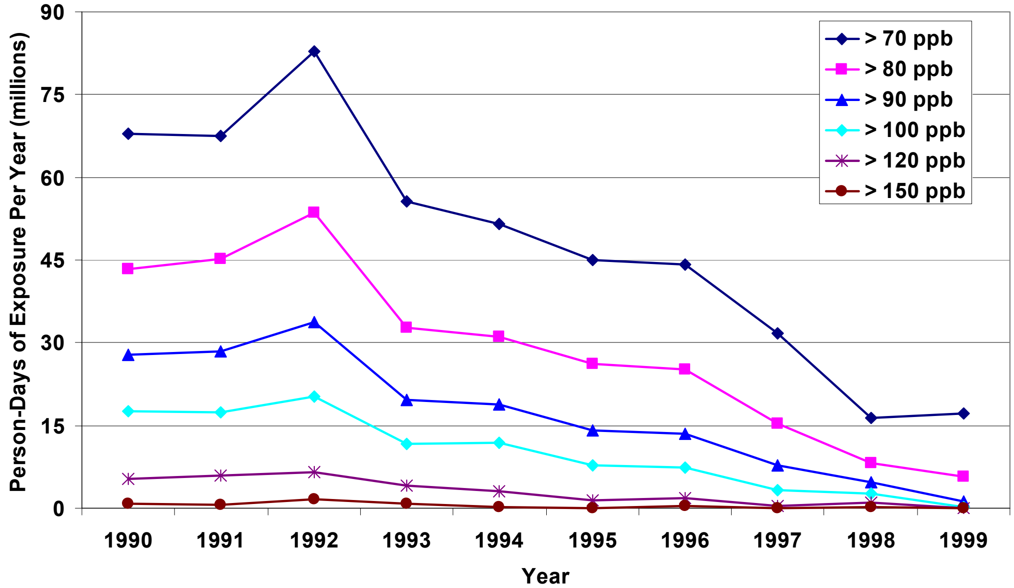


**Figure 2.5. Estimated 10 A.M. - 6 P.M. ambient ozone exposures for children on school days 1990 - 1999 in the SoCAB.**

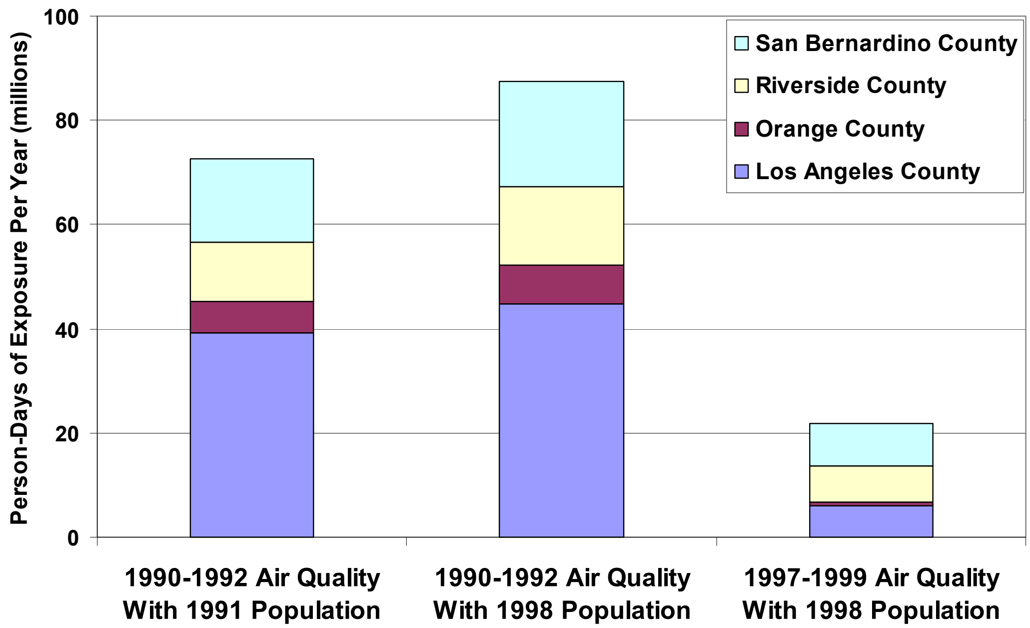


**Figure 2.6. Estimated children's 10 AM - 6PM ozone exposures above 70 ppb on school days in the SoCAB.**

## 2.2 Health Effects

A wide array of adverse heath effects is associated with exposure to ozone. Much of the research that establishes these associations has been done to determine where to set ambient air quality standards. Consequently, this research was designed primarily to establish thresholds for safety, rather than to investigate the association between changes in pollutant concentrations and changes in the frequency of effects. Nonetheless, many of these studies can be used to develop quantitative associations between ambient concentrations and adverse health effects at commonly experienced pollution levels. In this section, we describe:

- The health science literature that supports the setting of standards and, more generally, the scientific basis for accepting the association between ozone exposure and adverse health effects.
- The specific studies and exposure-response relationships used to quantify the frequency of ozone-related adverse health effects in children living in the SoCAB.

### 2.2.1 Establishing Concentration-Response Associations

The concentration-response relationships used in this research are derived from papers that have been published in the peer-reviewed literature and have also been reviewed through public scientific review processes including the U.S.EPA's Clean Air Science Advisory Committee and Council on Clean Air Act Compliance Analysis of the Science Advisory Board, the National Academy of Sciences, and the Health Effects Institute. Inclusion of epidemiological studies was restricted to those that gave adequate consideration to potentially confounding variables. Such confounders include weather-related variables, age and gender mix of the subject population, and pollutants other than ozone that might reasonably have effects on the health response being evaluated.

### 2.2.2 Scientific Basis for Associating Ozone with Health

Recent studies have reported statistically significant relationships between adverse health effects in humans (for example, as measured by hospital admissions) and ambient ozone concentrations well below 100 parts per billion (ppb) (see, for example, the U.S. EPA *Ozone Criteria Document* (1996), and the references cited therein). These studies have precipitated a major reappraisal of the air-quality goals, standards, and policies related to ozone. In the United States, the 1-hr, 0.12-ppm NAAQS for ozone has been supplemented with an 8-hr, 0.08-ppm standard.[1]

Ozone has been extensively evaluated in laboratory animal and human clinical studies, as well as in epidemiological studies. There is little doubt that ozone can damage lung tissue, cause symptoms in children and adults and exacerbate diseases such as asthma and bronchitis. The role of ozone as an agent that causes (rather than

[1] The NAAQS are stated in units of ppm and to two significant figures. Thus, 1-hr and 8-hr exceedances are technically defined as a concentration of at least 0.125 and 0.085 ppm, respectively; (i.e., concentrations that, when rounded to two significant figures, yield values equal to or greater than 0.13 and 0.09 ppm).

exacerbates) lung or heart disease is less clear, despite the fact that some specific mechanisms by which ozone injures the lung could also be related to the development of disease. The effects of ozone have been demonstrated to increase with increasing dose and studies have clearly demonstrated effects at concentrations of 80 parts per billion.

### 2.2.3 Ozone Effects in Children

A number of studies report significant increases in symptoms following exposure to ozone in schoolchildren, day camp children, asthmatic children and wheezy children, as well as significant decrements in at least one type of lung function. (Berry et al., 1991; Braun-Fahrlander et al., 1994; Buchdahl et al., 1996; Castillejos et al., 1992; Gielen et al., 1997; Higgins et al., 1990; Hoek et al., 1993; Kinney et al., 1996; Krzyzanowski et al., 1992; Neas et al., 1995; Ostro et al., 1995; Romieu et al., 1996, 1997; Spektor et al., 1991; Stern et al., 1994; Thurston et al., 1997; Ulmer et al., 1997). Significant increases in hospital admissions for children following ozone exposure have also been reported (Pönkä 1991; Burnett, et al. 1994; Romieu, et al. 1995; and White, et al. 1994). Much of the earlier literature is summarized and discussed in Bates (1995a, b, c).

There is sufficient quantitative information to establish concentration-response functions specifically for children to support quantifying benefits related to three effects that can be valued in economic terms: 1) reduced respiratory-related hospitalizations, 2) reduced asthma-related emergency room visits, and 3) decreases in school absences.

### 2.2.4 Deriving Concentration-Response Functions

To quantify the expected differences in respiratory-related hospital admissions and asthma-related emergency room visits, we have used two of the basic linear concentration-response functions developed by the U.S.EPA for use in the Second Prospective Analysis, (U.S. EPA, 2001) which evaluates the benefits and costs from 2000 to 2020 of air quality programs implemented under the Clean Air Act. The sources for these functions are described below.

#### Respiratory Hospital Admissions

While associations between hospital visits and air pollution have been reported for many different locations over the past 20 years, one of the largest databases analyzed comes from a series of studies of southern Ontario (Canada) hospital admissions. In one of that area's most comprehensive studies, Thurston et al. (1994) examine summertime air pollution and daily hospital admissions for respiratory causes in Toronto, Ontario. In the study a series of regression analyses indicate that ozone levels are consistently significant in explaining respiratory hospital admissions, even after controlling for temperature (a common confounding factor in such analyses). Moreover, the ozone association remains strongly significant even after excluding days with maximum one-hour ozone levels in excess of 120 ppb, and after conducting a series of simultaneous pollutant regressions, which incorporate a number of other pollutant measures. The authors conclude that ozone clearly dominates the summertime air pollution association with respiratory admissions.

The regression coefficients estimated in Thurston et al. provide a linear exposure-response relationship that forms the basis for our calculation of reductions in hospitalizations from improved air quality (ozone) conditions. Specifically, the function developed is the following:

$$\Delta H = \beta_H \ \Delta O_3^{1-hr} \ P$$

where:

| | | |
|---|---|---|
| $\Delta H$ | = | Change in all respiratory-related admissions |
| $\beta_H$ | = | Exposure-response factor ($1.68 \times 10^{-8}$) |
| $\Delta O_3$ | = | Change in daily 1-hour maximum ozone concentration (ppb) |
| $P$ | = | Affected population size (children, aged 5-18). |

The $\Delta O_3$ is calculated for cases where the base period daily maximum 1-hr ozone concentrations exceeded 90 ppb. Applying this function to all school-aged children in the SoCAB gives us the expected reduction in respiratory hospital admissions due to declining ozone levels.

**Emergency Room Visits**

Numerous studies have established a relationship between increases of ozone and a variety of asthmatic symptoms. In one of the more comprehensive works undertaken to date, Weisel et al. (1995) conduct a five-year retrospective study of the relationship between summer ozone concentrations and asthma-induced emergency room (ER) visits. Specifically, they examine the relationship between ambient ozone levels and ER visits by asthmatics in central New Jersey for five consecutive years, 1986 to 1990. Regression analyses are conducted using forward stepwise regression for each year, generating positive and significant coefficients of daily ER visits with ozone concentration. The results indicate that an increase of between 0.3 and 0.8 visits per day is associated with each 0.01 ppm increase in ozone. Moreover, their work supports the proposition that ozone adversely affects asthmatics at levels below the federal standard.

Again, the regression coefficients estimated in Weisel et al. provide a linear exposure-response relationship that forms the basis for our calculation of reductions in asthma-related emergency room visits from improved air quality (ozone) conditions. The specific function developed is as follows:

$$\Delta ER = \frac{\beta_{ER}}{P_{base}} \Delta O_3^{5-hr} \ P$$

where:

| | | |
|---|---|---|
| $\Delta ER$ | = | Change in asthma-related emergency room visits |
| $\beta_{ER}$ | = | Exposure-response factor (0.0443) |
| $P_{base}$ | = | Baseline population in N.J. (4,436,976) |
| $\Delta O_3$ | = | Change in daily five-hour average (10 A.M. – 3 P.M.) ozone concentration (ppb) |

$P$ = Affected population size (children, aged 5-18).

The $\Delta O_3$ is calculated for cases where the base period 5-hr ozone concentrations exceeded 70 ppb. Applying this function to all school-aged children in the study area gives us the expected reduction in asthma-related emergency room visits due to decreasing ozone concentrations.

**School Absences**

The Children's Health Study recently collected six months of data on school absences, and the reasons for those absences, for a cohort of children who were part of an active surveillance system including schools in 12 California communities with differing concentrations of multiple pollutants. This detailed assessment allowed Gilliland et al. (2001) to assess whether or not there was any association between pollution levels and absences, the size of any association and the type of absence. The patterns of school absences were not significantly associated with ambient $NO_2$ and $PM_{10}$ mass concentrations. However, ozone averaged over the period from 10 a.m. to 6 p.m. was "strongly associated with illness-related absences and especially with respiratory absences." Illness-related absences rose 62.9 percent for a 20 ppb increase in ozone concentrations while respiratory illness-related absences rose 82.9 percent (Gilliland et al., 2001). Combining these associations with the type-specific incidence of absences reported and changes in exposure to ozone over time, it is possible to estimate reductions in absences related to improvements in air quality. The relationship takes the form:

$$\Delta A_i = \beta_i \; I_i \; \left(\Delta O_3^{8-hr}\right) P$$

where:
- $\Delta A_i$ = Change in the number of type "i" absences
- $\beta_i$ = Exposure-response factor for absence type "i"
- $I_i$ = Baseline incidence rate for absence type "i"
- $\Delta O_3$ = Change in daily 10 AM - 6 PM average ozone concentration (ppb)
- $P$ = Affected school-day population size (children, aged 5-18).

The absence-specific baseline incidence rates and concentration-response factors are shown in Table 2.3. Note, the number of absences in the base period and future period are calculated only for cases where the 10 A.M. – 6 P.M. ozone concentrations exceeds 70 ppb.

**Table 2.3. Baseline incidence rates and concentration-response functions for ozone-related school absences.**

| Type of Absence | Exposure Response Factor ($\beta_i$) | Baseline Incidence Rate ($I_i$) | Combined Factor ($\beta_i I_i$) |
|---|---|---|---|
| All Illness | 0.03145 | 1.64% | $5.16 \times 10^{-4}$ |
| Nonrespiratory Illness | 0.01865 | 0.06% | $1.12 \times 10^{-5}$ |
| All Respiratory Illness | 0.04145 | 1.04% | $4.31 \times 10^{-4}$ |
| Upper Respiratory Illness | 0.02255 | 0.93% | $2.10 \times 10^{-4}$ |
| Lower Respiratory Illness/Wet Cough | 0.08695 | 0.18% | $1.57 \times 10^{-4}$ |
| Lower Respiratory Illness/ Wet Cough/ Asthma Attack | 0.03240 | 0.30% | $9.72 \times 10^{-5}$ |

## 2.3 ECONOMIC VALUES

Why do we assign dollar values at all, and what is the basis for those values? The most basic answer to the first question is that society does not have the material resources to do all of the good things that we would like to be able to do. Therefore, we must choose among competing uses for our scarce resources. This is true of individuals and of society as a whole. The objective of placing dollar values on reduced health risks is to help determine whether resources are being used well. If we cannot do all good things, we can at least attempt to do as many and as much as possible, which implies a need to know the relative value of different actions.

Regarding the second question, we want a systematic way to make collective (social) choices, so we need to decide which environmental protections are the most worthwhile, in this case, which ones will return the greatest value in improved health. We therefore need a means of comparison that is transparent, uses the best available information, and reflects social preferences. We also need a common denominator - a basis for comparison to weight each option, and so we use dollars as the denominator.

To decide what dollar value to place on an adverse health effect, we begin with the premise that, with limited exceptions, we accept individual choices as valid. Other than restrictions like speed limits and proscriptions against murder and some environmentally harmful actions, we assume that what individuals choose to do accurately represents what is best for them, and by reference, for society. In economic benefit assessment, the sum of value to individuals equals social value. We use prices (or implied prices) and surveys to value changes in air pollution-related risks to health.

The objective of this research is a dollar measurement of the benefits of fewer ozone-related adverse health effects in children resulting from lower levels of air pollution. This requires determining how much value we place on avoiding of ozone-related effects including hospitalizations, emergency room visits, and school absences. For each effect value is gained from reducing:

- Direct medical costs and loss of work and school days that result from avoiding or treating adverse health effects.
- Discomfort, inconvenience, and fear resulting from adverse health effects, their treatment, or efforts to avoid them.
- Loss of enjoyment and leisure time.
- Impacts on others as a result of adverse health effects experienced by a child.

### 2.3.1 Concepts and Measures

Ideally, measurements of value would capture all of the losses to individuals and to society that result from adverse health effects. They would also reflect as closely as possible real preferences and decision-making processes similar to those we use daily to decide everything from where to live to what to have for dinner. Purchases of goods or services are based on which items give the most satisfaction, or utility, relative to prices and income. Prices paid are accepted as reasonable measures of the value of those items that can be purchased. However, clean air (like many other environmental goods) is an item for which no well-defined markets exist. Values for such goods cannot be assumed from directly observed prices. Economists have therefore developed alternative methods to measure the value of environmental benefits, including health improvements resulting from cleaner air.

Two generally accepted economic measures of changes in well-being (utility) due to 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)) measure. Both measures have drawbacks and weaknesses but, when used in conjunction, yield a reasonable range of values for the health benefits of improvements in air quality.

Actual data on health care costs and wages are used to calculate COI measures. WTA and WTP measures are calculated from either market-based (hedonic) studies or contingent valuation (survey) studies. Market-based approaches estimate value from the economic consequences of actual and observed behavior in relation to differing levels of risk. In comparison, contingent valuation studies rely on surveys of a sample of the affected population to elicit WTP or WTA for a good such as improved air quality that cannot be purchased in a market.

In this research, we use COI measures, along with estimates of children's exposure and resulting adverse health impacts, to estimate the economic benefits of reduced ozone levels.

**Cost of Illness**

The COI method was the first economic valuation method to be developed and described in the health and safety literature. It involves calculating direct medical costs and indirect costs (lost wages) due to illness. This method is still 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. This method basically defines 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 effect of illness and malaise on the well being of a child, his or her family, and the larger society.

The minimum value to avoid the adverse effects of unhealthful air quality is reflected in the estimated direct and indirect COI measures. Other factors, most notably the perception of lost utility or welfare that is associated with illness, can result in 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.

A number of valuation studies indicate that only about one-half of an individual's WTP is typically captured by the COI approach (Chestnut et al., 1988; Rowe and Neithercut, 1987). For example, Dickie and Gerking (1991) estimated that the ratio of WTP to COI for reduction in ozone-related symptoms ranges from two to four for normal and respiratory-impaired individuals in California.

Other studies provide evidence that the difference between COI and WTP is much wider for more serious health endpoints, such as hospital admissions. The WTP of parents of children with elevated lead levels is 2-20 times the cost of chelation therapy (Agee and Crocker, 1996). Clearly, COI measures represent an incomplete picture of the losses caused by deteriorating air quality. Nonetheless, they are used when more complete economic measures are unavailable for an effect. While COI measures generally represent a lower bound of value, using them allows the valuation of many adverse effects, such as hospitalizations and emergency room visits, which would otherwise not be quantified.

### 2.3.2 Specific Values Used in This Study

Reductions in acute or chronic illness or symptoms are important components of the welfare gain resulting from reduced risks to health. Morbidity effects are departures from "a state of physical or mental well-being, resulting from disease or injury, of which the affected individual is aware" (Peterson, 1975). Specific health conditions and symptoms such as eye irritation, cough, exacerbation of asthma, and hospitalization for respiratory conditions are reported by many health studies as evidence of ozone-related morbidity effects. The recent health literature (Gilliland et al., 2001) has added ozone-related school absences.

The cost of illness literature addresses two general categories of costs--direct and indirect. Direct costs include medical and illness-related expenditures made by patients, insurance companies, and government agencies, and typically include: hospital care (inpatient and outpatient), services of physicians and other health care professionals, and medication and related equipment. Indirect costs are calculated as some form of the wage rate multiplied by the time lost from work. These are important to include because certain health outcomes, such as children's school absences, emergency room visits, and extended hospital stays, result in work loss, or equivalent restrictions on activity on the part of the caregiver parents or guardians. Wages represent the payment necessary to compensate workers for giving up non-work activities, and the minimum value of a day's productivity. Sick pay and vacation pay prevent a direct loss of pay for many workers, but the value of foregone work output is still an important loss to the economy. We note that using foregone wages probably produces a conservative estimate of the value of avoiding these health outcomes, since they only reflect the value of time given to one missed workday, and do not include the distress, worry, or overall disutility associated with an illness to one's child.

**Economic Unit Values**

In the U.S.EPA analytical plan (U.S. EPA, 2001), as part of the proposed morbidity valuation strategy for the Second Prospective Analysis of the Clean Air Act, the U.S. EPA recommends that the work of Smith et al. (1997) be used to generate dollar values for asthma-related emergency room visits. The peer-review body for the Second Prospective, the Science Advisory Board Council on Clean Air Compliance Analysis, accepted this approach. The Smith et al. work provides a detailed examination of national cost and resource utilizations by persons with asthma. It uses the cost of illness technique to account for direct medical expenditures, which include payments for hospital inpatient stays and emergency room visits, and indirect medical costs, resulting from missed work or school and days with restricted activity at work. Smith et al. compile an extremely detailed estimate of these costs by using expenditure-based data from the 1987 National Medical Expenditure Survey (NMES), a national probability sample of approximately 35,000 subjects representative of the noninstitutionalized, civilian U.S. population. Moreover, this survey collected data not only on all health care expenditures, but also information on demographics and income, allowing for the valuation of the indirect cost items.

Based on the comprehensive nature of the Smith et al. study, we draw on this work to derive not only dollar estimates for emergency room visits, but also for ozone-related school absences (referred to as school loss days in the Smith et al. study). For both health outcomes, point estimates and 95 percent confidence intervals are reported, allowing us to construct low, mid, and high dollar estimates.

**Asthma-Related Emergency Room Visits**

Smith et al. calculated the direct cost of approximately 1.2 million asthma emergency room visits to be \$348 million, with a 95 percent confidence interval ranging from \$244.8 million to \$451.1 million (all in 1994 dollars). Thus, the per visit direct cost ranges from \$204 to \$375.92, with a "best" estimate of \$290 (again, in 1994 dollars). We note that this figure does not include the direct cost of any medicines prescribed for the patient to be taken after the ER visit, thereby imparting a conservative bias to the number.

We adjusted these Smith figures in two ways. First, the 1994 dollar values were updated to 2000 dollars, using the CPI-U, medical care category, for the LA/Anaheim/Riverside metropolitan area. Second, to account for the fact that this is a *child's* visit to the emergency room, we included a lost productivity effect to reflect the time lost from work by one of the caregiver parents or guardians. Fifty percent of the median daily wage rate of one caregiver was applied to each ER visit. Final asthma emergency room visit dollar values, by county, appear in Table 2.4 below.

**Table 2.4 Value of avoiding an emergency room visit (\$2000)[a,e].**

| County | Low Estimate | Mid Estimate | High Estimate |
|---|---|---|---|
| Los Angeles[b] | \$305.93 | \$407.66 | \$509.26 |
| Orange[c] | \$302.39 | \$401.12 | \$505.72 |
| Riverside, San Bernardino[d] | \$297.12 | \$398.85 | \$500.45 |

a) The 1994-2000 cost adjustment factor was 1.1827.
b) The lost income for Los Angeles County residents was \$64.66.
c) The lost income for Orange County residents was \$61.12.
d) The lost income for Riverside and San Bernardino County residents was \$55.85.
e) Sources: For the CPI-U, medical care figures--*California Statistical Abstract*, California Department of Finance, multiple years; for the SoCAB median wages figures--1999 *Metropolitan Area Occupational Employment and Wage Estimates, Occupational Employment Statistics*, U.S. Bureau of Labor Statistics).

**Ozone-Related School Absences**

To value missed school days for children 5 to 17 years of age, Smith et al. estimated lost productivity to the parent or guardian, under the assumption that they stayed home to take care of their sick child. In situations where two caregivers were involved, the lower income was used to estimate lost productivity. In cases where one of the parents did not have any income (about 39 percent of the survey responses), an imputed value for housekeeping was utilized.

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), with a 95 percent confidence interval ranging from \$123.9 million to \$265.1 million. This translates into a per-day value of $54.03, with "high" and "low" values of $73.64 and $34.42 (again, in 1994 dollars).

To apply these national figures to our analysis, two adjustments were then made. First, the number were updated to 2000 dollars, using the percentage change in an index of California Median Household Income. Second, they were modified to recognize the slightly higher median incomes earned in some parts of southern California. Los Angeles and Orange County values were adjusted upward to reflect this difference. Riverside and San Bernardino County median incomes are very close to the U.S. average; therefore, these two counties required no income adjustment. The final dollar value calculations for ozone-related school absences appear in Table 2.5 below.

**Table 2.5 Value of a avoiding a school absence day ($2000)[a,c]**

| County | Low Estimate | Mid Estimate | High Estimate |
|---|---|---|---|
| Los Angeles[b] | $51.58 | $80.97 | $110.36 |
| Orange[b] | $48.75 | $76.54 | $104.32 |
| Riverside, San Bernardino | $44.52 | $69.89 | $ 95.26 |

a) The 1994-2000 income adjustment factor was 1.2936 for Southern California.
b) The income adjustment for Los Angeles and Orange County residents were 1.1585 and 1.0951, respectively.
c) Sources: *Median Household and Family Income*, California Department of Finance, Demographic Research Unit, multiple years; also U.S. Department of Commerce, Bureau of the Census.

**Hospital Admissions--All Respiratory**

To develop a dollar estimate for a respiratory hospital admission, we use information from the 1999 California Hospital Discharge Data, a data collection that contains annual, non-confidential hospital patient discharge data for the State of California. These data are edited by the California Office of Statewide Health Planning and Development and verified by individual hospitals. Profiled variables include patients' length of stay, major diagnostic category, and total charges. We note that the charge figures provided in the data set represent total direct costs for the hospitalization and do not include the indirect cost of lost caregiver time--a day spent in the hospital by a child results in at least one caregiver adult spending part of the day at the hospital also.

In the 1999 California Hospital Discharge Data, the daily average costs of an acute respiratory admission and a chronic admission are reported to be $3,696.49 and $3,236.13, respectively. We elected to use the average of these two costs, since the health study providing us with the concentration-response function (Thurston et al., 1994) looks at *all* respiratory-related admissions. Since the average daily cost for chronic admissions is slightly lower than the cost for acute admissions, this imparts a slight conservative bias to our cost estimate. Our average cost of a hospital admission is thus estimated to be $3,466.31 (measured in 1999 dollars). [2]

With these hospital charges as a starting point, we then made two modifications for our analysis. First, we converted the figures into 2000 dollars, using the CPI-U, Medical care category, for the United States. Then, to account for the fact that this is a child's hospital stay, we again included a lost productivity factor. To capture the time lost from work by at least one of the caregivers, we applied fifty percent of the median wage rate for each day of hospital stay. The average length of stay reported in the California Discharge Data for a respiratory hospital admission is 7 days; we therefore included 3.5 days of lost income as an indirect cost of the hospital admission. County-specific total dollar values for respiratory hospital admissions are presented in Table 2.6.

**Table 2.6 Value of avoiding a respiratory hospital admission ($2000)[a].**

| County | Dollar Estimate |
|---|---|
| Los Angeles[b] | $25,712 |
| Orange[b] | $25,687 |
| Riverside, San Bernardino[b] | $25,650 |

a) The 1999-2000 adjustment factor = 1.041.
b) The lost income figures for Los Angeles, Orange, and Riverside/San Bernardino Counties were $454.62, $472.84, and $390.95, respectively.

### 2.3.3 Issues in Valuation

It is important that the values for each adverse health effect reflect as closely as possible the value that society places on reducing the frequency of effects related to ambient ozone concentrations. Because we have little direct evidence of the value adults place on their own health, and because we extrapolate from the values evidenced in adults to children, it is also important to be aware of the primary sources of upward and downward bias that might be introduced by use of any particular value. Some issues specific to a particular measure are discussed above. Here, we address some broader issues.

There will always be some uncertainty regarding the closeness of value estimates, from any method, to the "real" value of avoiding some health effects. The issues discussed below reflect other ways in which real and reported values might differ. Conclusions about the net effect on final estimates of divergences between "real" and estimated values cannot be made. This is because there is no established basis to make

[2] We note here that the US EPA, as part of its proposed morbidity valuation strategy for the Second Prospective Analysis of the Clean Air Act, recommended that the work of Elixhauser et al. (1993) be used to value hospital admissions. Since we have 1999 California-specific cost figures for hospital admissions, however, we elected to use the California Hospital Discharge Data in our calculations.

numerical adjustments. We know, for example, that there are important health endpoints (such as loss of lung function) that are not quantified in dollar terms. We also know that the value of reducing risk to health likely varies with age, but the values commonly used are based on adults. We do not know how these factors jointly impact the degree to which aggregate estimates of value diverge from "real" values.

**Unquantified effects**

The adverse health effects whose frequency in association with air pollution can be quantified, and whose avoidance can also be valued in dollars, is a limited subset of the total set of adverse effects that have been observed or measured in epidemiological, human exposure, or animal studies. Limitations of both health science and economics contribute to our inability to quantify these effects. Reduced lung function, for example, which has been linked to ozone in a number of health studies, cannot be easily valued in economic terms. Moreover, we simply have no way to calculate the relative importance of what is measurable and what is not, so it is impossible to determine how large the unquantified effects may be in economic terms. In addition, some of the unquantified effects may overlap some effects that are quantified. For example, changed pulmonary function accompanies chronic asthma. Nonetheless, it is important to recognize the number and nature of such unquantified effects to provide perspective when interpreting the meaning and comprehensiveness of estimates of the economic value of improved air quality.

Currently, unquantified ozone-related effects include: lower respiratory symptoms, immunological changes, chronic respiratory damage and disease, inflammation of the lung, increased airway responsiveness, and changes in pulmonary function.

**The effect of altruism**

In addition to the downward bias introduced by omitted effects, we make no adjustment for altruism. A number of studies indicate that individuals are willing to pay more than the direct value to themselves to reduce risk to others. Jones-Lee (1992) reports that in a "caring society" the value of risks to the lives of others is 110-140 percent of the value based on pure self-interest. As Viscusi et al. (1988) point out, however, these percentages cannot be treated as universal constants and therefore cannot be extrapolated to values for effects and circumstances not reflected in the studies that find such percentage differences between self-interested and altruistic values. In another study, Jones-Lee et al. (1985) found that the amount people were willing to pay to reduce risks to anonymous others was about one-third of what they were willing to pay to reduce similar risks to themselves. This result reflected, in part, what Viscusi (1986) called "the altruistic concerns of society at large." We did not include the altruistic value of protecting children's health in the economic estimates for the reasons noted above. Available evidence suggests, however, that the benefits would be larger if such an adjustment were made.

**Other sources of uncertainty**

An important issue is the existence of health effects thresholds, that is, pollution levels below which there are no further beneficial health benefits to be realized from increased controls. The fact that most empirical studies that link pollution to adverse health effects come from epidemiological studies, where researchers cannot control exposure, makes it particularly difficult to determine whether or not there are health effect threshold levels. A consistent association between ozone and health effects has been found by recent health studies, even at pollution levels well below most air quality standards. The existence and level of thresholds remains an important source of uncertainty in health estimation, for if no threshold is assumed, but one exists, benefits will be overestimated. Conversely, if a threshold is imposed where one does not exist, the predicted health benefits resulting from an improvement in air quality could be seriously underestimated. In this study we have reported on some evidence of ozone-related health effects below the federal standard.

Benefit assessments depend heavily on epidemiological studies, many of which show statistical associations between pollutants and a number of common health effects, including increased hospital visits and admissions. What makes the use of these associations somewhat problematic is that significant overlap may exist in the estimated benefits attributed separately to reductions in ozone concentrations. Here, we have accounted for overlapping symptoms between hospital respiratory admissions and asthma-related emergency room visits by adjusting emergency room visits downward to reflect those that progress to hospitalization. In future valuation efforts, this overlap issue may carry further importance, as statistical associations are now being increasingly found between ozone and higher mortality risk—ozone-related mortality will increasingly be included in benefit assessments. The health studies used in this analysis were chosen in part for their efforts to address this issue and to control for multiple pollutants.

## 3.0 RESULTS

The benefits of fewer adverse health effects can be measured in several ways, in both the actual differences in the number of such effects and in the economic value of those differences. Differences can also be viewed at the basin level and at the county level, and as aggregate or per capita differences. The results of this study are reported by all of these measures.

The air quality comparison used to estimate differences in the number of effects is the change between ozone concentrations in a series of three year base intervals and the three year interval 1997-1999. The initial base period is 1990-1992. Subsequent base intervals compared to 1997-1999 are 1991-1993, 1992-1994, and so on. Because we want to know how many fewer effects there are now than there would have been had air quality not improved significantly, *the 1998 population is used in all base years*. Estimated differences therefore show how many fewer adverse effects there were in the 1997-1999 period compared to how many there would have been in that interval had ozone levels not in fact fallen from earlier intervals. All results are for children aged 5-18. The comparison between the initial base period, 1990-92, and 1997-99 provides the basis for the economic valuations that follow. Dollar values are reported in year 2000 dollars.

The results reported here were obtained from the SYMVAL model. The SYMVAL model is uses the REHEX model output files and the concentration response factors to estimate differences in symptoms and economic values on three geographic scales: individual exposure district scale, county scale, and air basin scale. The model also calculate the per capita differences for each scale. For simplicity, the individual county and air basin (or 4 county) results are reported here.

### 3.1 Decreases in the Number of Ozone-related Adverse Health Effects

The adverse effects that are quantified in this study include school absences, respiratory-related hospital admissions and asthma-related emergency room visits. Each of these, as discussed in section 2.2, can be estimated based on the peer-reviewed health literature specific to children

#### 3.1.1 School Absences.

The results for all-illness absences are shown in Table 3.1. These results are broken down by category of illness in Table 3.2. The estimates in Table 3.2 total more than the estimate for all-illness absences because there is some overlap in the categories of illness (Gilliland et al., 2001). All results are shown as aggregate differences by county and as per capita differences by county. In addition to differences in absences over the entire interval, the pattern of decreases over time is shown for the basin in Table 3.3.

**Table 3.1 Differences in annual ozone-related all-illness school absences from 1990-1992 to 1997-1999 in the 1998 population aged 5-18.**

| School Absences | Basin | Los Angeles County | Orange County | Riverside County | San Bernardino County |
|---|---|---|---|---|---|
| Total for All Illnesses | 3,190,200 | 1,824,000 | 282,000 | 430,800 | 653,400 |
| Per capita | 1.0 | 0.9 | 0.5 | 1.3 | 1.6 |

**Table 3.2 Differences in annual ozone-related school absences by category of illness from 1990-1992 to 1997-1999 in the 1998 population aged 5-18. Per capita differences are shown in parentheses.**

| School Absences | Basin | Los Angeles County | Orange County | Riverside County | San Bernardino County |
|---|---|---|---|---|---|
| Absences for Nonrespiratory Illness | 692,000 (0.2) | 395,600 (0.2) | 61,170 (0.1) | 93,470 (0.3) | 141,700 (0.4) |
| Absences for All Respiratory Illnesses | 2,666,000 (0.8) | 1,524,000 (0.8) | 235,700 (0.4) | 360,000 (1.1) | 546,100 (1.4) |
| Absences for Upper Respiratory Illness | 1,312,000 (0.4) | 744,900 (0.4) | 115,900 (0.2) | 177,200 (0.5) | 268,700 (0.7) |
| Absences for Lower Respiratory Illness/Wet Cough | 967,800 (0.3) | 553,300 (0.3) | 85,550 (0.2) | 130,700 (0.4) | 198,200 (0.5) |
| Absences for Lower Respiratory Illness, Wet Cough, and Asthma | 601,100 (0.2) | 343,600 (0.2) | 53,140 (0.1) | 81,190 (0.2) | 123,100 (0.3) |

**Table 3.3 Differences in ozone-related all-illness school absences in the South Coast Air Basin over time for the 1998 population aged 5-18 in millions of annual absences**

| Time Period | 1990-92 To 1997-99 | 1991-93 To 1997-99 | 1992-94 To 1997/99 | 1993-95 To 1997-99 | 1994-96 To 1997-99 | 1995-97 To 1997-99 | 1996-97 To 1997-99 |
|---|---|---|---|---|---|---|---|
| Decreases in All-Illness Absences | 3.19 | 2.84 | 2.47 | 1.70 | 1.43 | 0.984 | 0.480 |

### 3.1.2 Hospitalization and Emergency Room Visits

This set of adverse health effects is more serious than the illnesses that result in additional days of absence from school. However, for a given level of ozone they will occur less frequently so as ozone levels fall the decreases in these effects will be relatively smaller. Estimated differences in these effects are shown in Table 3.4.

**Table 3.4 Difference in annual ozone-related emergency room visits and respiratory-related hospital admissions from 1990-1992 to 1997-1999 for the 1998 population aged 5-18**

| Symptom | Basin | Los Angeles County | Orange County | Riverside County | San Bernardino County |
|---|---|---|---|---|---|
| Emergency room visits | 167 | 108 | 16 | 17 | 26 |
| Hospitalizations | 387 | 237 | 38 | 42 | 70 |

## 3.2 The Economic Value of Fewer Ozone-related Adverse Health Effects

### 3.2.1 School Absences

As discussed in section 2.3.2, a school absence imposes an economic cost both in terms of direct health care expenditures and in terms of the time that a caregiver must divert from other activities to care for the child. Consequently, for large differences in absences the economic benefits are substantial. Because information regarding medical treatment associated with illness-related school absences is not available, *the only economic benefit included in these results of the value of the caregiver's time*. These results are shown in Table 3.5. The economic value of fewer school absences is estimated only for all-illness absences because adding the value of each subcategory of illness would overstate the total value.

**Table 3.5 Economic value of differences in annual 8-hour ozone-related all-illness school absences from 1990-1992 to 1997-1999 in the 1998 population aged 5-18**

| School Absences | Basin | Los Angeles County | Orange County | Riverside County | San Bernardino County |
|---|---|---|---|---|---|
| Total all illness | $245,048,000 | $147,689,000 | $21,584,000 | $30,109,000 | $45,666,000 |
| Per capita all illness | $75 | $74 | $39 | $91 | $114 |

Table 3.6 shows a range of values for this benefit. The range is based on the 95 percent confidence interval reported in Smith et al.

**Table 3.6 Range of economic values of differences in annual ozone-related all-illness school absences from 1990-1992 to 1997-1999 in the 1998 population aged 5-18**

| **School Absences** | **Low** | **Mid** | **High** |
|---|---|---|---|
| **Total All Illness** | $156,098,004 | $245,048,000 | $333,995,772 |
| **Per Capita All Illness** | $48 | $75 | $102 |

### 3.2.2 Hospitalization and Emergency Room Visits

These effects carry significant costs both in terms of medical care and caregiver time. Consequently, the value per event is high, but the number of events is relatively small. The economic value of decreases in these effects from 1990-1992 to 1997-1999 is shown in Table 3.7. Again, these values are not simply summed because an emergency room visit can lead to hospitalization, so aggregating these results could lead to double counting. An adjustment factor of 0.63 is applied, representing the fraction of emergency room visits that do progress to hospital admissions (U.S. EPA 2001). Consequently, the total economic benefit of reductions in these two effects is less than the sum of the separate effects.

**Table 3.7 Economic value of differences in annual ozone-related emergency room visits and respiratory-related hospital admissions from 1990-1992 to 1997-1999 for the 1998 population aged 5-18**

| Symptom | Basin | Los Angeles County | Orange County | Riverside County | San Bernardino County |
|---|---|---|---|---|---|
| 1. Emergency room visits | $67,595 | $44,027 | $6,418 | $6,780 | $10,370 |
| 2. Emergency room visits adjusted for overlap | $42,584 | $27,737 | $4,043 | $4,271 | $6,533 |
| 3.Hospitalizations | $9,942,650 | $6,093,744 | $976,106 | $1,077,300 | $1,795,500 |
| Total 2+3 | $9,985,234 | $6,121,481 | $980,149 | $1,081,571 | $1,802,033 |

### 3.3 Overall Benefits

Overall benefit estimates are shown in Table 3.8. The total annual benefits estimated to have resulted from lower concentrations of ambient ozone over the last decade are centered on more than $255 million for the basin.

### 3.4 Benefits from Reduced Absences with Attainment of the State 1-hour Standard

The results reported above describe the difference in the frequency of school absences in the 1998 school-aged population associated with falling ozone levels from 1990 to 1999. It is also of policy interest to know what the additional benefits might be if the Basin were in attainment with the state 1-hour standard. For all-illness school absences, the additional annual benefits are shown in Table 3.9. These estimates are predicated on rollback of the 1-hour maximum concentration of 244 ppb in 1997-1999 to 95 ppb, a threshold of 70 ppb, and a background concentration of 40 ppb.

**Table 3.8 Aggregate economic value of differences in annual ozone-related emergency room visits, respiratory-related hospital admissions, and school absences from 1990-1992 to 1997-1999 for the 1998 population aged 5-18**

| Symptom | Basin | Los Angeles County | Orange County | Riverside County | San Bernardino County |
|---|---|---|---|---|---|
| Adjusted emergency room visits and hospitalizations | $9,985,000 | $6,121,000 | $980,000 | $1,082,000 | $1,802,000 |
| School absences | $245,048,000 | $147,689,000 | $21,584,000 | $30,109,000 | $45,666,000 |
| TOTAL | $255,033,000 | $153,810,000 | $22,564,000 | $31,191,000 | $47,468,000 |

**Table 3.9 Benefits of differences in annual 8-hour ozone-related all-illness school absences from 1997-1999 to attainment of the 1-hour state standard in the 1998 population aged 5-18.**

| School Absences | Basin | Los Angeles County | Orange County | Riverside County | San Bernardino County |
|---|---|---|---|---|---|
| Difference in all-illness absences | 931,400 | 253,900 | 29,100 | 296,200 | 352,100 |
| Economic value of reduced absences | $67,910,000 | $20,557,000 | $2,226,000 | $20,701,000 | $24,608,000 |

## 4.0 DISCUSSION OF RESULTS

### 4.1 Absences

Clearly, fewer school absences associated with falling ozone levels are a significant benefit for the region's school children. From 1990-1992 to 1997-1999 there were almost 3.2 million fewer absences annually, which is about one less absence for each child, on average. The largest benefits by county are in Los Angeles and San Bernardino; however, on a per capita basis, the benefits were larger Riverside and San Bernardino Counties than in Los Angeles and Orange Counties. In Los Angeles County, annual absences were 1.8 million fewer, and in San Bernardino County more than 650,000 fewer. In Riverside County, which has a somewhat smaller population, the estimated reduction in absences is 430,000. These reductions are the result of both population size and patterns of ozone concentrations relative to population. Had today's population experienced 1990-1992 ozone levels in those counties, absences would have been much more frequent. Orange County experienced smaller differences because pollution levels were already lower than elsewhere in the basin in the base interval. Consequently, the total difference, while significant at more than 280,000, is proportionately smaller.

The pattern of differences in absences over time tracks the pattern of falling ozone concentrations in the basin. The large number of standard violations in the early 1990s means that the reductions achieved by the late 1990s result in many fewer school absences overall, and that the earlier years of the decade saw larger differences in the numbers of absences than in the later years.

While the total value of reduced absences is large, at nearly a quarter of a billion dollars for the mid-range estimate, it should be noted that this benefit estimate omits several factors that could be important. Medical treatment and caregiver time are limited measures of the cost of an absence. There are other impacts on a child's family that are not yet quantifiable, such as loss of leisure time and impacts on other children in a household. More important, illness and increased absences have been associated with erosion of longer-term life attainment (Rozelle et al., 1968; Shogren, 2001) that in turn relates to lifetime achievements and overall life satisfaction. These changes in life chances are consequences on which economists cannot yet place a dollar value, but which are recognized as important (Sen, 1999). Further, each absence here is treated as if only one day of school is lost per absence. To the extent that absences are multi-day, this represents an underestimate of actual benefits. Finally, all estimates relating to absences are based on this effect only occurring on weekdays when schools are in session. Logically, the illnesses that lead to school absence do not occur only on weekends, but on any day with ozone above the threshold for that effect. Consequently, medical cost and diversion of caregiver time from other activities are reduced more overall by falling ozone concentrations than is reflected in the value of decreased school absences alone.

### 4.2 Hospitalization and Emergency Room Visits

These effects are triggered by higher ozone concentrations than are school absences. Consequently, they are much less frequent so differences in these effects are relatively small, even for large improvements in air quality. On an annual basis, there were 387 fewer respiratory-related hospitalizations and 167 fewer emergency room visits for children in the basin as a result of air quality improvements from 1990-92 to 1997-99. The economic benefits of these reductions combined are nearly $10 million annually

### 4.3 Future Benefits

While falling ozone levels in the 1990s clearly contributed to significant benefits to the health of schoolchildren, the basin continues to have many days each year when the state 1-hour ozone standard is violated. Consequently, attainment of the standard would generate additional benefits, reducing school absences by nearly 1 million annually, with an economic value of approximately $68 million. While benefits would accrue across the basin, the largest benefits would be in Riverside and San Bernardino Counties because the school-aged population there was exposed to more days above the 1-hour standard in 1997-1999, the base period, than elsewhere in the basin.

## 5.0 SUMMARY AND CONCLUSIONS

### 5.1 Results

The results show that there have been significant benefits to schoolchildren in the South Coast Air Basin as ambient ozone levels have fallen over the past decade. For the 1998 school-aged population, there would have been three million more school absences annually in 1999 had ozone levels not decreased from the baseline interval of 1990-92 to 1997-99 levels. As population increased and more children enrolled in year round and summer school programs, the benefits of ozone reductions increased relative to air quality improvements. The economic value of fewer school absences ranges from just under $157 million to more than $333 million annually, with a best estimate of $245 million. This represents a benefit of nearly $75, on average, for every school child in the region.

Less frequent, but more serious adverse health effects associated with ozone exposure include respiratory-related hospitalizations and emergency room visits. Annual reductions for these effects are 387 and 167, respectively, representing economic benefits of nearly $10 million annually.

The pattern of benefits across countries is consistent with the changing pattern and level of ambient ozone and population growth over the past decade. All counties have benefited, with the largest benefits in Los Angeles County, with both the largest population and the largest absolute decline in the number of days on which the state and federal ozone standards were violated.

### 5.2 Implications

As the school-aged population increased and year round and summer school programs expanded from 1990-1999, ozone-related school absences would have significantly increased had ambient ozone levels not fallen significantly across the SoCAB. The economic value of the approximately 3.2 million absences avoided annually is $245 million. Ozone levels continue, however, to exceed one or more health-based standard in much of the region, suggesting that continuing air quality improvements will generate substantial further benefits for the school-aged population.

There are certain groups of people who are more likely to suffer adverse health effects than others following exposure to air pollution. Children are more vulnerable because of their physical immaturity, tendency to be more physically active, and time spent out of doors

An area of great concern to policy makers is risk to children. Traditionally, most of the emphasis in developing data for setting air quality standards has been on adults. More recently, however, awareness has grown that children cannot be considered “scaled-down” adults, and that more sophisticated approaches are necessary in order to accurately account for the effects of air pollution on them. While children inhale less mass of pollutant for a given exposure level than adults do, most physiological effects are dependent upon dose received. On this basis, the effective dose to a child's lung, in terms of pollutant received as a function of body weight, is usually greater than that for adults under similar exposure conditions. Moreover, lungs grow until the late teens or early twenties. If air pollution influences the growth process, resulting in smaller lungs, vitality is at risk. Children are more impacted by a given level of pollution because of their physiology and tendency to be active and out of doors.

At the same time that they are more vulnerable, there is evidence that both families and society place more weight on avoiding an adverse health effect in a child than in an adult. Consumers with young children report a WTP for safer consumer products that is two to four times higher than the WTP of households without children (Viscusi et al., 1987). In a later study 75 percent of respondents indicated willingness to pay for child-risk reductions outside their own households (Viscusi et al., 1988).

More recently, an international valuation study (Liu et al., 2000) found that mothers were willing to pay twice as much to protect their children as they were to protect themselves from suffering a minor respiratory illness.

Children, along with members of ethnic minorities, might also be more at risk because they live in sections of urban areas with worse than average air quality. A number of studies suggest that exposure to riskier levels of pollution is greater for lower income groups, ethnic groups, and children (Brajer and Hall, 1992; Korc, 1996).

Poorer groups tend to be more exposed because housing costs correlate to some degree with pollution. To the extent that minorities are more likely to be poor, they will also be differentially exposed to higher levels of pollution. To the extent that poorer families are larger than average, more children will also be differentially exposed.

## 5.3 Future Research Needs

There are significant gaps in the knowledge and information available to assess the benefits from improvements in air quality. Robust estimation of economic value depends first on air quality monitors that represent the exposure population reasonably well and on a good understanding of how exposure changes as population and pollution patterns are changing. Given good estimates of how exposure changes over time, we next need a health effects base that is congruent with our exposure data – one that assesses effects relative to equivalent chemical composition of the atmosphere, averaging times, and age distribution of the population. Finally, for each health endpoint that can be related to pollution exposure in a region we also need an economic value that represents the dollar benefits of reducing the occurrence of that endpoint as exposure declines. Several suggestions for priority research needs follow.

- As described in Section 2.2, there are myriad adverse physiological responses to pollutant exposure. Many of these – structural changes in the lungs and airways, reduced lung function, and immune system responses, for example – are logically related to illness and school absences. We presently, however, have no economic knowledge about what the benefits would be of preventing these responses.

Therefore, one important area of further research is interdisciplinary work by health scientists and economists to better model the link between physiological change and adverse health outcomes and to design contingent valuation studies to then determine the value of avoiding the more subtle pre-clinical effects.

- In this study, we have relied on linear dose-response functions. The health literature contains a number of nonlinear functions, which could expand and refine the set of health outcomes considered. The use of these non-linear functions, however, requires information, such as detailed baseline incidence rates, and was beyond the scope of this study.

- Society places significant weight on protecting children, but we have almost no basis to determine how to value, for example, chest symptoms in children relative to the adults on whom values are now based. Given the demonstrated sensitivity of asthmatic children, and the higher doses of pollution experienced by children in general, relative to adults, this is a key area of investigation.

- Emissions reductions will often reduce multiple pollutants simultaneously, but we typically assess the benefits of reducing one pollutant at a time. More investigation is needed of the joint value of reducing a set of adverse effects, rather than single effects.

- The literature on child development is just beginning to provide a basis to quantify the effects of school absences on life achievements. Presently, we can only capture the short-term benefits of reduced absences, but the longer-term benefits could well be a significant component of the total benefit of reducing this adverse effect.

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## Glossary

| | | |
|---|---|---|
| Ambient | = | Outdoor |
| AQS | = | Air quality standards |
| COI | = | Cost of illness |
| REHEX | = | Regional Human Exposure model |
| Morbidity | = | Adverse health effects other than death |
| NAAQS | = | National Ambient Air Quality Standards |
| NMES | = | National Medical Expenditure Survey |
| ppb | = | Parts per billion (in air) |
| SCAQMD | = | South Coast Air Quality Management District |
| SoCAB | = | South Coast Air Basin |
| SYMVAL | = | Symptom Valuation Model |
| U.S. EPA | = | United States Environmental Protection Agency |
| WTA | = | Willingness to accept |
| WTP | = | Willingness to pay |